60 e. h.

THE

ASSISTANT ENGINEER'S

RAILWAY GUIDE;

CONTAINING INSTRUCTIONS FOR

SETTING OUT THE LINES AND LEVELS OF RAILWAY WORKS;
IN CUTTINGS, EMBANKMENTS, AND PERMANENT WAY;
BRIDGES AND VIADUCTS, ON THE SQUARE,
ON THE SKEW, AND ON CURVES.

WITH NUMEROUS NOTES, TABLES, AND PRACTICAL OFFICE RULES FOR
DESIGNING OR CALCULATING THE STRENGTH OF
RAILWAY WORKS IN

Stone, Brick, Wood, or Iron;

TABLES OF EARTHWORK SECTIONAL AREAS, AND GRADIENTS.

Illustrated by upwards of 120 Woodcuts.

BY W. DAVIS HASKOLL, C.E.

TO WHICH HAVE BEEN ADDED,

TEN SETS OF EXPERIMENTS ON THE STRENGTH OF MATERIALS,
BY GEORGE RENNIE, Esq., F.R.S., M.I.C.E.,

AND

THREE PLATES AND SPECIFICATION, ILLUSTRATIVE OF THE
CONSTRUCTION AND DETAILS OF THE LAMINATED ARCH
FORMING THE BRIDGE OVER THE OUSE, ON
THE EAST ANGLIAN RAILWAY,
J. S. VALENTINE, Esq.

PART II.

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CHAPTER I.

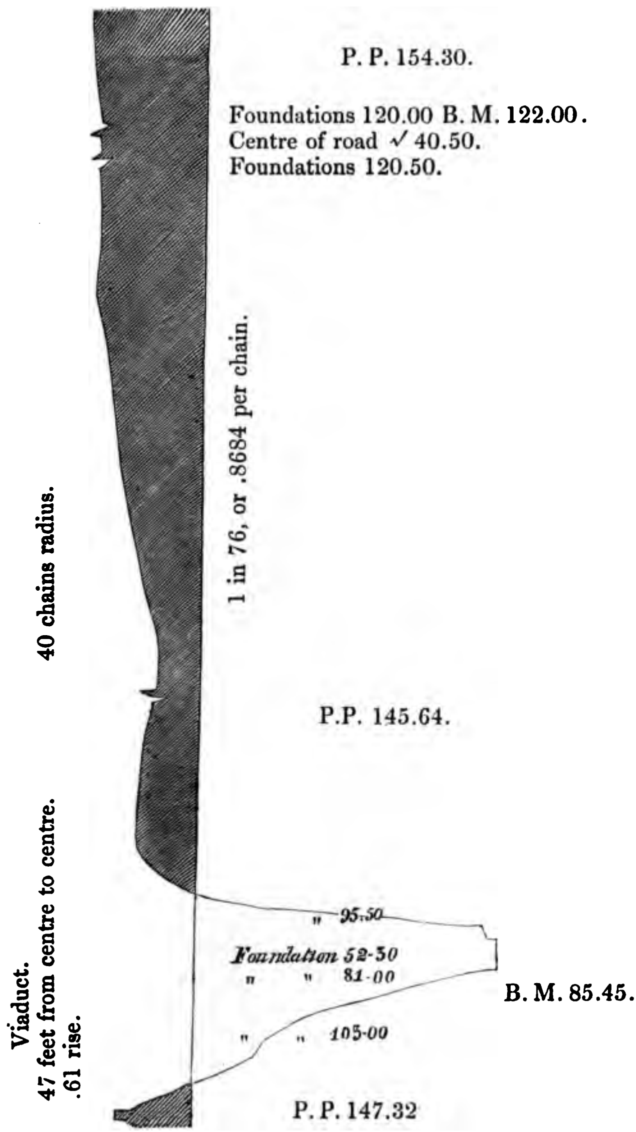
Pocket Section—Setting out Levels of Cuttings and Embankments, Viaducts, Bridges, &c.

1. In the first part of the "Assistant Engineer's Railway Guide," the principally intended purpose was to give instructions to the *uninitiated* with regard to the methods most usually employed by practical men to ascertain by "boring," the nature of subsoils, stratification, foundations, &c.; to set out the tangents and curves of the permanent centre line of an intended railway; to take the levels for the working section, the art of levelling being supposed known to the reader; and to set out the widths required for the slopes of excavations and embankments. On these subjects we will simply repeat at present, that in taking the levels, particularly over a rough country, the permanent posts, which are to be referred to as so many bench marks, should not be more than 10 or 12 chains apart; that there should be one at each end of every cutting, near every road to be crossed, at both ends of all viaducts and tunnels; that they should be well secured from mischief, and at sufficient distance from the foundations, so that they need not be interfered with by excavating; and if these works are to be of any magnitude, there should be sufficient intermediate posts. As the levels of these important constructions will be obtained from these posts, too

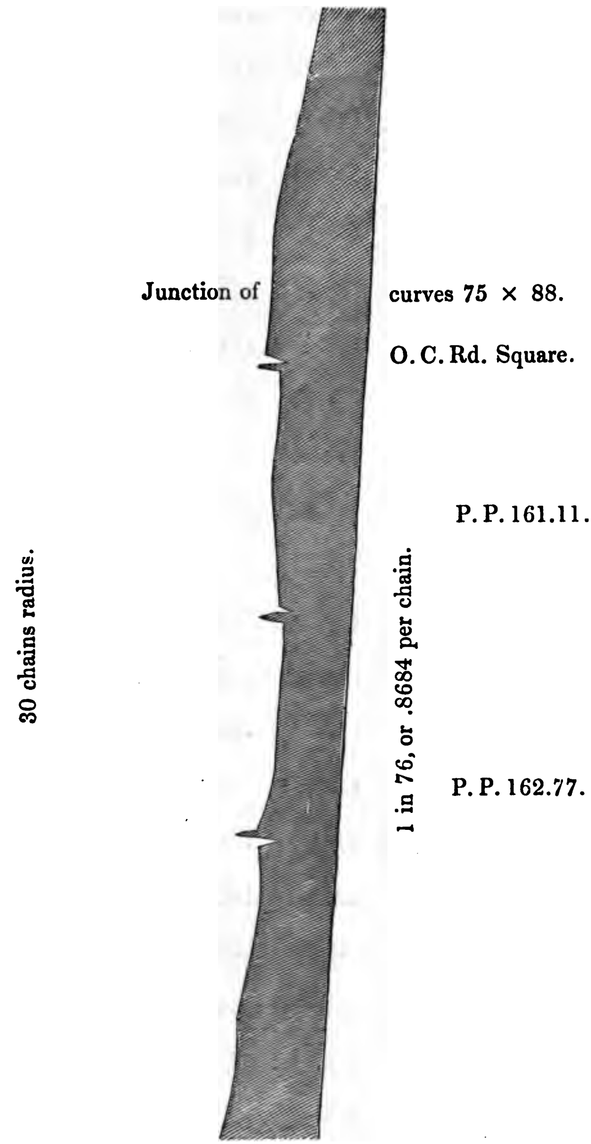
much care cannot be bestowed in obtaining their real height as referred to datum. Let me persuade the young practitioner, that the gratification he will feel at finding the string courses of his bridges and viaducts at their true height and gradient, the formation of a tunnel at the intended levels, will alone amply reward him for his trouble, independently of a reputation for accuracy, which he will not fail to obtain in the opinion of a judicious chief, as also in the estimation of directors. Let him beware of the vaunts of "rough-and-ready men," (*rough* work and *readiness* to blunder), who disguise their incapacity and ignorance by pleading the impossibility in practice to obtain truly correct levels; for if there be any truth, rationally speaking, in this excuse, the greater should be the engineer's care to avoid errors, and not to do his work in a slovenly manner, whereby he may double and treble his "*mistake*"; and he will find that contractors, masons, bricklayers, &c., will be careful and attentive exactly in proportion to the care and attention which he himself bestows on the works. This observation applies exactly in the same sense, and to same extent in setting out works. He will, moreover, have the satisfaction of knowing, that his mind on this subject will be at ease as the works proceed, and that no reproach can be made to him; on the contrary, an error of this kind carried out can be considered little better than wilful neglect of duty.

2. The levelling book of the working section, with a correct sketch of the ground, or a pocket section, is constantly required on the works. The following is one of a most useful kind; it is prepared after the section has been plotted, and the gradients laid down. The angles formed by the nick with existing roads and rivers, or streams, should be entered, and the number of the drawing referring to the same as soon as prepared. The depths of cuttings and heights of embankments are also set down in their proper columns, and in that headed "distance" is noted the chainage where the nick intersects walls and fences. By the help of this, when stumps and level pegs have been long removed, their position with regard to distance may at any time be found. As soon as the widths have been set out, according to instructions given in the first part, these, also, can be set

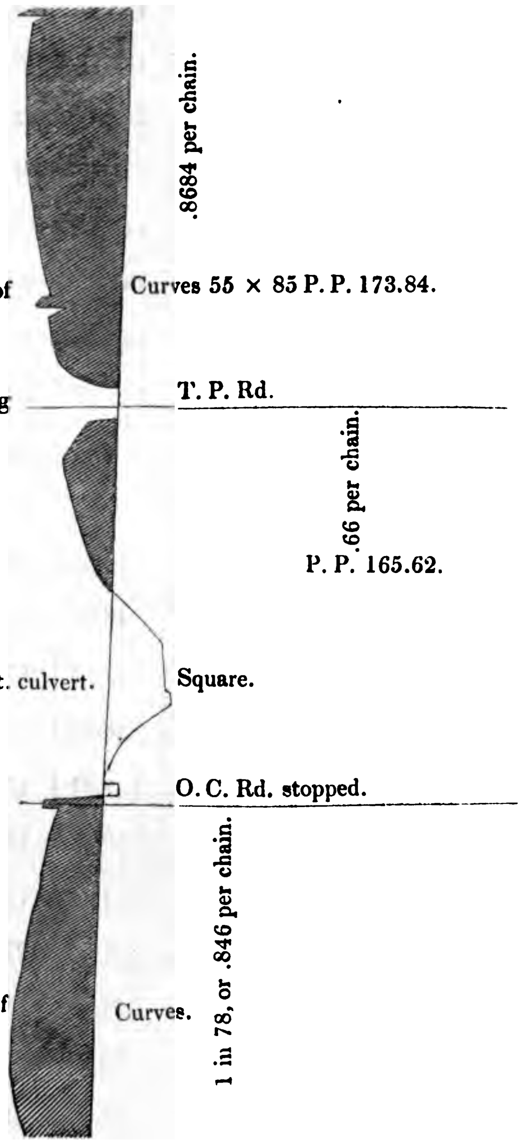
down in the half width columns; also the cubic quantities per chain in their proper column, as soon as they have been ascertained, which, where the earth work is heavy, particularly in sidelong ground, should always be admeasured from cross sections, taken at every chain stump, at the earliest opportunity. All bench marks given for the guidance of the excavators, masons, &c., should be entered in this book, with the date, as, also, any memoranda with regard to the nature or state of the works; it should be a register always ready for inspection, as well as for verification of the accuracy of his operations in very many respects.


P. P. 154.30.
Foundations 120.00 B. M. 122.00.
Centre of road √ 40.50.
Foundations 120.50.
1 in 76, or .8684 per chain.
40 chains radius.
P.P. 145.64.
" 95.50
Foundation 52-50
" " 81-00
" " 105-00
B. M. 85.45.
Viaduct.
47 feet from centre to centre.
.61 rise.
P. P. 147.32

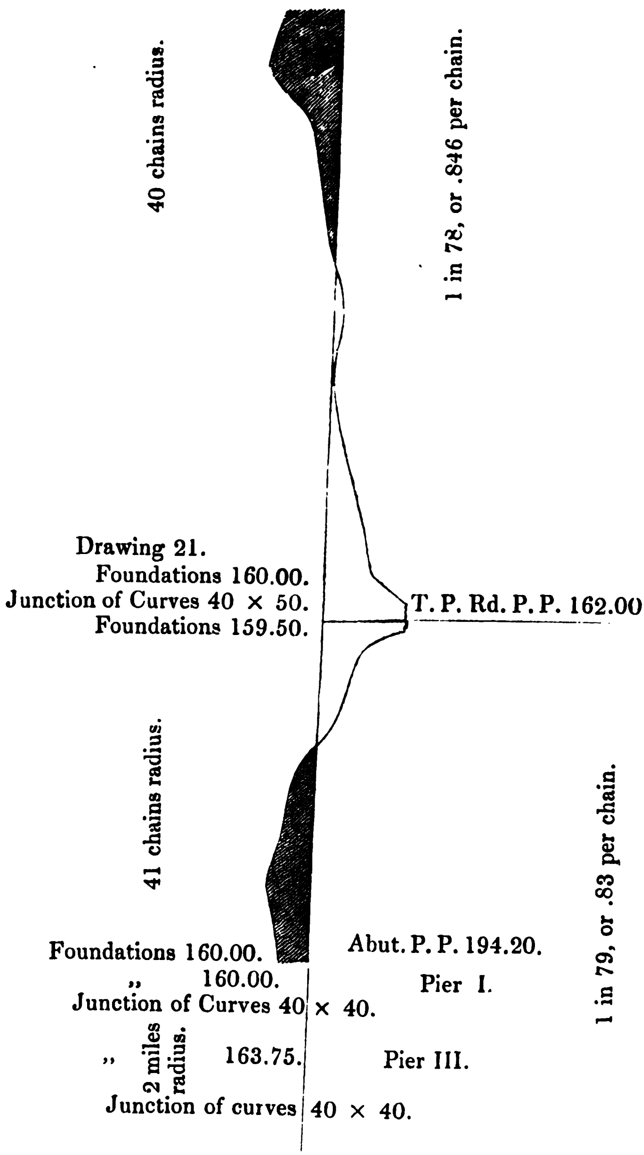
Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
63.00	66.75	2M.39Ch	150.95	119.08	31.87	
61.00	64.50	40.00	150.50	119.94	30.56	
61.00	55.00	41.00	148.57	120.81	27.76	
		41.40				
64.75	58.00	42.00	150.33	121.68	28.65	
65.00	50.00	43.00	149.70	122.55	27.15	
63.50	50.00	44.00	152.14	123.42	28.72	
63.50	52.95	45.00	151.44	124.29	27.15	
60.65	48.55	46.00	151.13	125.15	25.98	
57.75	44.85	47.00	149.53	126.02	23.51	
53.00	40.70	48.00	147.95	126.89	21.06	
50.00	37.70	49.00	145.73	127.76	17.97	
43.75	34.30	50.00	143.88	128.63	15.25	
37.70	25.70	51.00	139.88	129.50	10.38	
		51.25				
36.50	28.25	52.00	141.13	130.36	10.77	
41.25	30.75	53.00	144.38	131.23	13.15	
44.45	33.20	54.00	146.38	132.10	14.28	
		55.00	122.40	132.97	- -	10.57
		56.00	52.30	133.84	- -	81.54
		57.00	102.80	134.71	- -	31.91
		58.00	9.42	135.57	3.85	
		59.00	152.20	136.44	15.76	


Junction of curves 75 × 88.
O. C. Rd. Square.
P. P. 161.11.
30 chains radius.
1 in 76, or .8684 per chain.
P. P. 162.77.

Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
33.00	40.00	60.00	156.68	137.31	19.37	
43.50	42.50	61.00	159.12	138.18	20.94	
		62.00	162.39	139.05	23.34	
48.50	51.50	63.00	164.80	139.92	24.88	
		64.00	166.35	140.79	25.56	
49.50	59.00	65.00	166.65	141.65	25.00	
		63.30				
49.00	60.00	66.00	164.34	142.52	21.82	
43.70	56.00	67.00	164.54	143.39	21.15	
42.50	51.00	68.00	165.25	144.26	20.99	
38.50	47.65	69.00	163.65	145.13	18.52	
		69.70				
34.00	45.80	70.00	162.10	146.00	16.10	
33.00	45.00	71.00	161.85	146.86	14.99	
		72.00	163.13	147.73	15.40	
35.05	45.30	73.00	165.12	148.60	16.52	
		73.62				
		74.00	167.70	149.47	18.23	
35.75	48.00	75.00	167.91	150.34	17.57	
		76.00	171.04	151.21	19.83	
40.35	56.25	77.00	173.30	152.07	21.23	
		78.00	174.41	152.94	21.67	
44.00	59.00	79.00	175.77	153.81	21.26	
		3 Miles.	179.81	154.68	25.13	


30 chains radius.
.8684 per chain.
Junction of
Curves 55 × 85 P. P. 173.84.
Level crossing
T. P. Rd.
30 chains radius.
.66 per chain.
P. P. 165.62.
Brook 6 ft. culvert.
Square.
O. C. Rd. stopped.
1 in 78, or .846 per chain.
Junction of
Curves.

Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
47.00	60.00	1.00	179.40	155.55	23.85	
47.50	59.00	2.00	181.64	156.42	25.22	
42.90	61.55	3.00	181.76	157.28	24.48	
43.80	61.25	4.00	182.10	158.15	23.95	
39.50	53.00	5.00	179.02	159.02	20.00	
36.40	51.00	6.00	177.50	159.89	17.61	
		6.10				
31.75	45.39	7.00	176.47	160.76	15.71	
		8.00	161.62	161.63		
27.75	41.25	9.00	174.54	162.29	12.25	
24.00	40.00	10.00	171.70	162.95	8.75	
18.75	38.00	11.00	166.39	163.61	2.78	
42.00	37.00	12.00	150.83	164.27	- -	13.44
		13.00	147.80	164.93	- -	17.13
		14.00	161.80	165.59	- -	3.79
		14.70				
24.50	24.00	15.00	172.12	166.25	5.87	Change gradient 646.
		16.00	179.75	167.09	12.66	
		17.00	182.11	167.94	14.17	
		18.00	185.73	168.78	16.95	
		19.00	187.46	169.63	17.83	
		20.00	188.93	170.48	18.45	
		21.00	186.75	171.32	15.43	


40 chains radius.
1 in 78, or .846 per chain.
Drawing 21.
Foundations 160.00.
Junction of Curves 40 × 50.
Foundations 159.50.
T. P. Rd. P. P. 162.00.
41 chains radius.
1 in 79, or .83 per chain.
Foundations 160.00.
Abut. P. P. 194.20.
„ 160.00.
Pier I.
Junction of Curves 40 × 40.
„ 163.75.
2 miles radius.
Pier III.
Junction of curves 40 × 40.

Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
		22.00	185.41	172.17	13.24	
		23.00	190.41	173.03	17.38	
		24.00	180.90	173.86	7.04	
		25.00	179.42	174.71	4.71	
		26.00	177.22	175.55	1.67	
		27.00	174.05	176.40	- -	2.35
		28.00	174.29	177.24	- -	2.95
		29.00	176.70	178.09	- -	1.39
		30.00	175.67	178.94	- -	3.27
		31.00	172.56	179.78	- -	7.22
		32.00	170.00	180.63	- -	10.63
		33.00	161.07	181.47	Change gradient 83 per ch.	20.40
		34.00	175.49	182.30	- -	6.81
		35.00	180.20	133.13	- -	2.93
		36.00	190.74	183.96	6.78	
		37.00	194.13	184.79	9.34	
		38.00	197.73	185.62	12.11	
		39.00	192.46	186.45		
		40.00	175.81	187.28		
		41.00	167.43	188.11		
		42.00	172.52	188.94		

Radius 40 chains.
Viaduct × Retaining wall.
.51 rise from centre to centre.
41 feet „ „

Found. 160.00.
„ 162.00.
„ 175.00.
„ 176.50.
„ 160.00.
„ 168.50.
„ 160.00.
„ 162.00.
„ 160.00.

Abutment.

Abut-
ment.
Pier I.
Pier II.
Pier III.
Pier IV.

1 in 79, or .83 per chain.

B. M. 183.
B. M. 172.80.
P. P. 180.42.
B. M. 168.26.
B. M. 170.10.
B. M. 161.15.

„ 165.00.
Junct. of curves.

Abutment.
70 × 30.

B. M. 182.30.

P. P. 179.00.

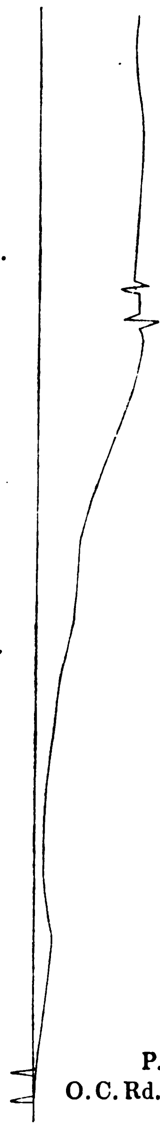
50 chains radius.

1 in 78, or .846 per chain.

Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
		43.00	171.62	189.77		
		44.00	177.75	190.60		
		45.00	182.79	191.43		
		46.00	185.27	192.46		
		47.00	174.52	193.09		
		48.00	170.50	193.92		
		49.00	165.53	194.76		
		50.00	165.81	195.59		
		51.00	158.49	196.42		
		52.00	172.77	197.25		
		53.00	168.09	198.08		
		54.00	175.37	198.91		
		55.00	179.79	199.75		
		56.00	177.73	199.96	Change gradient 84 per ch.	22.23
		57.00	178.95	200.80	- -	21.85
		58.00	179.10	201.65	- -	22.55
		59.00	179.33	202.49	- -	23.16
		60.00	178.12	203.34	- -	23.22
77.00	79.00	61.00	173.35	204.19	- -	30.84
		62.00	174.10	205.03	- -	30.93
72.00	73.00	63.00	177.35	205.88	- -	28.53

42 chains radius.

Drawing 12.
Found. 180.50 B.M. 187.00.
„ 172.00



O. C. Rd. Square.

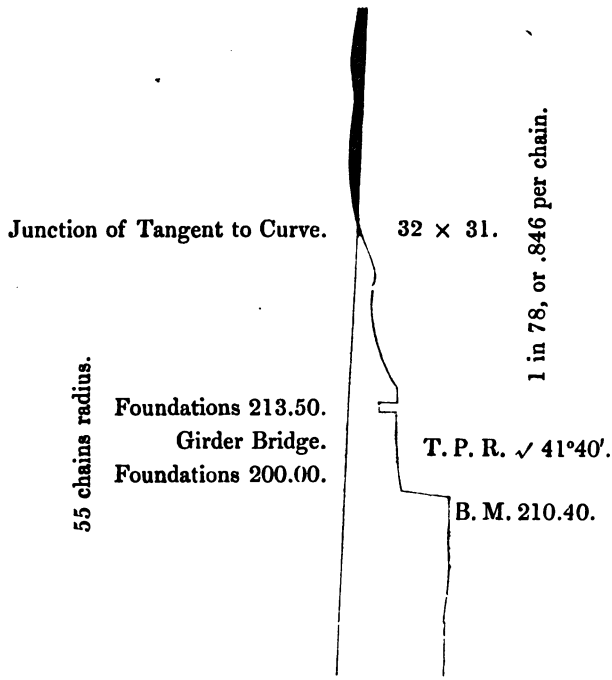
P. P. 188.15″.

1 in 78, or .846 per chain.

Junction of Curve to Tangent.

P. P. 222.90.
O. C. Rd. Square, Level Cross.

Half Widths.		Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
Left.	Right.					
65.00	67.75	64.00	180.25	206.72	- -	26.47
61.00	64.50	65.00	183.05	207.57	- -	24.52
63.00	66.00	66.00	182.88	208.43	- -	25.54
68.00	68.00	67.00	182.85	209.27	- -	26.42
		68.00	183.86	210.11	- -	26.25
65.50	66.00	69.00	185.77	210.95	- -	25.18
		69.40				
69.00	70.00	70.00	184.11	211.80	- -	27.69
65.50	65.50	71.00	187.12	212.65	- -	25.53
55.50	57.00	72.00	193.17	213.49	- -	20.32
47.00	49.00	73.00	198.57	214.34	- -	15.77
37.50	37.50	74.00	203.76	215.18	- -	11.42
35.00	36.00	75.00	205.75	216.03	- -	10.28
27.00	28.00	76.00	210.79	216.88	- -	6.09
		76.40				
25.50	25.50	77.90	212.34	217.72	- -	5.38
23.00	23.00	78.00	214.69	218.57	- -	3.88
20.00	20.00	79.00	216.75	219.41	- -	2.66
19.75	20.00	4 Miles.	217.52	220.26	- -	2.74
23.00	24.00	1.00	216.72	221.11	- -	4.39
19.00	20.25	2.00	219.61	221.95	- -	2.34
18.50	17.50	3.00	222.17	222.80	- -	.63
		3.65				
18.00	17.00	4.00	223.91	223.94	.27	


Junction of Tangent to Curve.
32 × 31.
1 in 78, or .846 per chain.
55 chains radius.
Foundations 213.50.
Girder Bridge.
Foundations 200.00.
T. P. R. ✓ 41°40′.
B. M. 210.40.

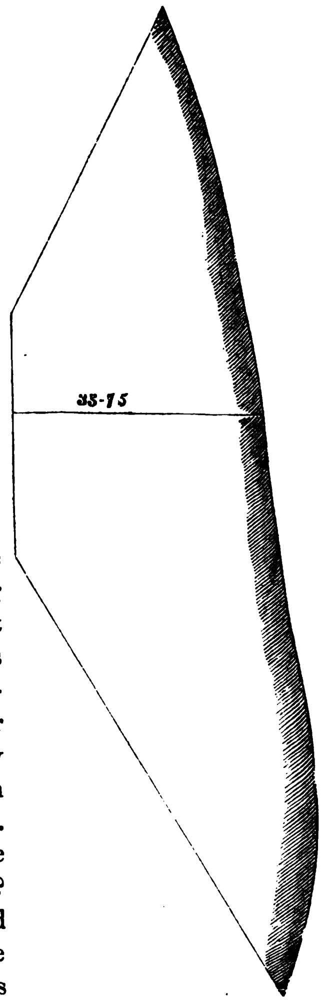
Half Widths. Left.	Half Widths. Right.	Distance.	Total Rise.	Finished Levels.	Excavation	Embankment.
17.00	17.00	5.00	225.48	224.49	.99	
19.00	20.25	6.00	227.94	225.34	2.60	
18.00	17.75	7.00	227.74	226.18	1.56	
17.00	17.75	8.00	228.57	227.03	1.54	
17.00	17.25	9.00	227.35	227.87	- -	.52
29.00	29.50	10.00	221.97	228.72	- -	6.75
29.50	31.00	11.00	222.01	229.57	- -	7.56
42.00	40.00	12.00	216.77	230.41	- -	13.64
		13.00	213.42	231.26	- -	17.85
68.00	71.25	14.00	204.80	232.10	- -	27.30
		15.00	205.08	232.95	- -	27.87
		16.00	206.20	233.80	- -	27.60
68.00	71.00	17.00	207.45	234.64	- -	27.19

3. The above portion of a section book shows part of a line now near completion; at page 4, chainage 2 miles 41.40, is a skew bridge, of which the angle is 40°.50′; at one side the depth of foundation is 120.00, and on the other side 120.50; a B.M. 122.00 above datum, was cut on the masonry which was 20 feet below the intended formation of over road. At 2 miles, 55.20 is the abutment of a viaduct with depth of foundation 95.00; formation here being 133.15, the depth of foundation was 38.15 below formation; but the rise with the thickness of arch stone is 15′ 6″, springer 1 = 16′.6″ to be deducted from 38.15 = 21.65, or 21′ 8″ below springer, which height should be inserted on the contractor's memorandum book, and signed by the engineer. The other piers and abutments should be treated in the same way. At 2 miles 64.00 is a junction of curves; two stumps, forming one line with the centre stump, have been driven in at the distance of 75 ft. on the left, and 88 ft. on the right, and these dimensions being booked, it is easy, as soon as required, to find this point, and to set out the curves for the permanent way. The same remarks occur further on, these distances being always marked by ×, the left side being always understood to be on one side of the line, and the right on the other, whichever way we may be looking, and this to avoid confusion of sides. These various notices of the requisite memoranda may appear trifling to old practitioners, but it must be remembered, that throughout these pages the information offered is not for them, but for those who have yet to learn, and these latter may believe the assurance made to them, that in systematically keeping all these notes and memoranda, they will ensure the readiest and the best means of preserving their work from uncertainty and confusion.

4. Cross sections should be taken from right to left, or left to right, through the centre line, particular care being given to note in the field book the direction in which this has been done, that they may be plotted in the same direction, and that it may at all times, and by any one, be known which is the right or left of the line shown by these sections; it is scarcely more necessary to add, that the chainage and levels at the centre must in particular be noted, in order that the proper depth may be set off at the distance, to show the quantity of excava-

tion, or embankment; for this purpose a card board templet, with a base of 30 ft., 31 ft., or 33 ft. as the case may be, made to a suitable scale with the slopes cut to the "ratio of slope," as 1 to 1, or 1½ to 1, as may be determined upon, will be found an accurate and expeditious little instrument. Fig. 1 will at once explain this. They must always be plotted to a natural scale; 20 ft. to the inch will not be found too large for accurate admeasurement of the sectional area, and for checking the setting out of slopes when this latter operation has been previously done. The cross sections must all be carefully numbered, and the numbers entered on the pocket section at their respective chain stakes. Where side cutting is expected, the cross sections must be produced, so that the quantities of excavation may be accurately ascertained therefrom. The levels for these cross sections must undeniably consume considerable time, but with irregular surfaces, as shown at Figs. 2 and 3, what other means are there of correctly ascertaining quantities? In one case the contractor suffers, and in the other great injustice is done to the company. Again, in cuttings of 30 ft., 40 ft., and 50 ft., where the spread from edge to edge of the slopes would be from 120 ft. to 180 ft., it is next to impossible when measuring up to obtain this length with accuracy, particularly in sidelong ground, and if we have a curved surface matters are still worse; hence difficulties, disputes, and litigation; even before the completion of works it is so easy, in case of uncertainty or variance in admeasurements, to set off any ex-

Fig. 1.



cavation in whatever state, and to obtain true quantities, that these documents are really invaluable. At the end of this

FIG. 2.

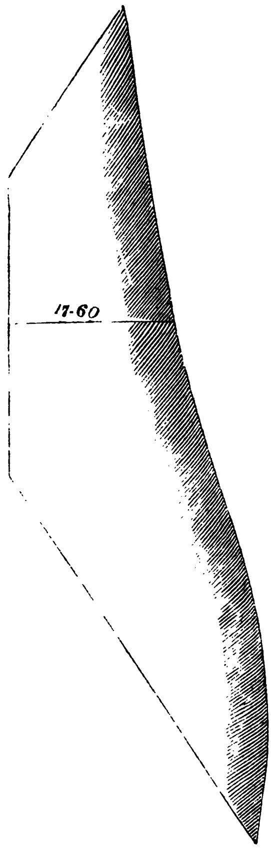
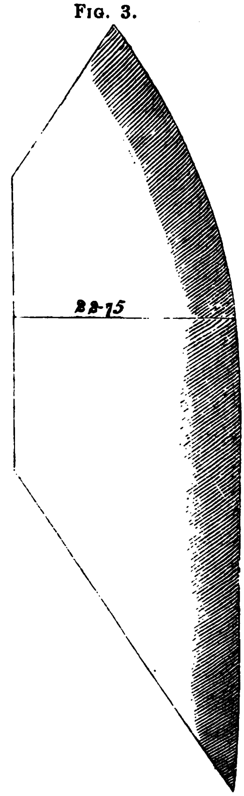


FIG. 3.

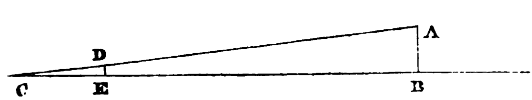


work will be found tables of sectional areas for the calculations of earthwork from these cross sections.

5. An inclined plane is one inclined to the horizon, and by the term "gradient," numerically expressed, we imply the proportion which the height of rise or fall of the inclined plane bears to the length of the said incline, as 1 in 100, 1 in 200, 1 in 300, are expressions which mean, that in 100 ft. the rise or fall is 1 ft., that in 200 ft. the rise or fall is 1 ft. &c., &c.; and by keeping 1 as a constant number, the various proportions which inclined planes bear to each other is better expressed and under-

stood than by varying both expressions, or employing fractional quantities. Having to ascend or descend to a given point above or below the starting point, and along a given route, we shall know by levels and measurements the height of ascent or descent, and the distance by which the difference of levels will be regulated into one or more inclined planes; for a short distance, and slightly undulating ground, this may often be done by one incline; for any considerable length, more particularly in a broken country, hills and valleys, rivers, canals, and roads, will compel us to consider these as guiding circumstances, or we must encounter innumerable tunnels and viaducts, and disproportionate cuttings and embankments, expensive bridges, and other crossings; but a well regulated series of inclined planes graduated in a measure proportionately to the inclination of hill and valley, skirting along the one and skimming over the other, and reaching from height to height, enable us, by moderate works, and therefore at a moderate expense, to attain the desired end; and generally the reaching from valley to hill, and hill to valley, the crossing of rivers and roads, the equalization of excavations and embankments, will be the existing circumstances in compliance with which certain heights are to be reached, and by which the inclined planes, and therefore the gradients, will be determined. The working section will show a vertical plane passing through these various points, the relative heights of which have been ascertained by levelling, and their distances from each other being known, it remains to calculate the gradients. At distance 3 miles 8.00, (page 8), there is an incline which is to reach from 161.64 above datum to 14.50 above a road, which is 6.50 links further on; the level of the road is 151.43 above datum, and $151.43 + 14.50 = 165.93$; but $165.93 = 161.64 + 4.29$, or the difference of level between a point we have reached on the section and one to be attained. But 650 links are equal to 429 ft., and this divided by 4.29, the difference of level will give 1 in 100 for the gradient; for $4.29 : 429 :: 1 : 100$, or $AB : BC :: DE : EC$;

FIG. 4.



therefore, in all cases, to find the ratio of inclination, or gradient, divide the length in feet by the rise or fall, and the quotient will be the answer; but having the gradient, or ratio of inclination, it is also necessary to know the rise or fall per chain, in order to calculate the depth of cutting or embankment, or rather the height of formation above datum, as this height, deducted from that of the surface above datum, will give the depth of cutting whilst the deduction of the height of surface from the height of formation will give the depth of embankment, as at 2 miles 10 chains $171.70 - 162.96 = 8.74$, or depth of cutting; and at 2 miles 12 chains $164.28 - 150.83 = 13.45$, or depth of embankment. To find the rise or fall per chain divide the difference of level by the number of chains in the incline, as $4.29 \div 6.50$.

```
6.50)4.290(.66
     3900
     ----
      3900
      3900
      ----
      0000
      ----
```

Therefore, to find the gradient, or ratio of inclination, divide the length of the incline in feet by the difference of level. And to find the rise or fall per chain, divide the difference of level by the number of chains, as shown above.

The ratio of inclination of a plane, or the gradient, being given to find the inclination per mile, divide the number of feet in a mile by the ratio, as

```
100)5280(52.8 per mile.
    500
    ---
     280
     200
     ---
      800
      ---
```

The gradient being given, to find the inclination in a chain,

divide 66 (the number of feet in a chain) by the ratio as for 1 in 100, 66 ÷ 100—

```
100)660(.66
    600
    ---
     600
     600
     ---
```

Also, the gradient being given, to know the rise or fall per yard, divide 3 (the number of feet in a yard) by the ratio, as in 1 in 100, what is the inclination per yard?

```
100)300(.03
    300
    ---
    000
    ---
```

And at any time, for any length, divide the length in feet by the ratio, as in 1 in 78, how much in 12?

```
78)12.0(.15 (sufficiently near for practice)
   78
   ---
   420
   390
   ---
```

In calculating the formation heights for the contract section, from which, as before observed, the depths of cuttings and embankments are afterwards ascertained, the greatest care is required in doing this correctly, for if, in this first step, an error be committed, it will be carried on into the depth of cutting or embankment, and the contractor working from such contract section may cut to a wrong depth, for which, in justice, he is in no way to blame; to men of habits at all careful, this may almost appear impossible, but it is nevertheless, however gross the blunder, one of common occurrence. At 2 miles 33 chains, let it be supposed that the formation height is marked 182.48 instead of 181.48, which it should be; now the heights for the springers would be set out by reference to bench marks, when the arch might be turned to a height of 21.41, instead of 20.41,

making the crown of the arch 1 ft. too high for 181.48 — 161.07 = 20.41; but 182.48 — 161.07 = 21.41. It is hoped that the importance of a careful calculation of the gradients at every chain stake is now distinctly understood; the ratio of inclination being ascertained, and the rise or fall per chain, every stump height will require to be calculated separately, and checked by tens, twentys, &c., and in as many places as possible—the reader may rest strictly and honestly assured, that for whatever trouble 20 or 30 miles of such calculations may give, he will be most amply repaid by ease of mind on this important subject during the working of the contract. From formation height 161.64, before referred to, we have an incline of .66 per chain for 7 chains; and $.66 \times 7 + 161.64 = 166.26$; but $161.64 + .66 = 162.30 + .66 = 162.96 + .66 = 163.62$, and so on until we have 166.26 at the 7th chain, if no error be made; on an incline of a greater length we check these results by multiplying the rise or fall per chain by 10, 20, 30, &c., which is very quickly done, and examining the 10th, 20th, or 30th chain stakes taken at different places. This being gone through, it only remains to get the depth of cutting by deducting formation height from the surface height, or the reverse, when we get the height of embankment.

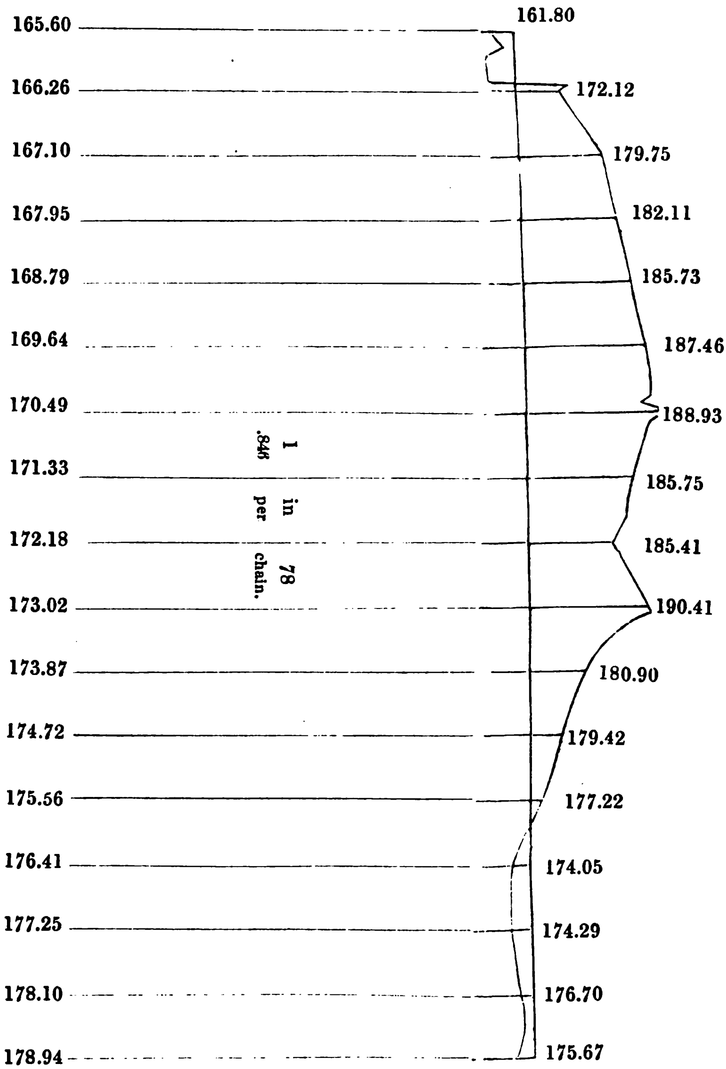
6. The pocket section being prepared so far, we should, as soon as the works of construction are determined on, insert notes from the working drawings or otherwise, of the angles of skew at which the line crosses roads, canals, &c., the spans of arches on the square and skew, the rise of the arch, the depth of arch stones, of puddle, if any; also, if the works be on an inclined plane, the rise or fall from centre to centre of piers; memoranda also, of nearly similar nature, should be made of girder bridges, culverts, drains, and other works occurring along the line. These remarks are more than necessary, because, when on the works, the drawings, when required, are often mislaid, or partially defaced or destroyed; it must be added, however reluctantly, that the tracings with which contractors and sub-contractors are supplied, are often wrongly figured, and the site of construction, amidst the moving to and fro of masons, labourers, and "navvies," is not the place where such errors may be most readily detected and corrected. The acting en-

gineer always affixes his signature to the working drawing, but not always to the tracings, the correctness of which is often entrusted to a confidential office assistant, but who, from want of field practice, is not always aware of the value of correct figures. The "Assistant Engineer" will find it advantageous, and only consistent with his duty, to compare the copy of contract works with the office original. Whilst on this subject it may be as well to mention, that the advice and hints thrown out in these pages are for the guidance or consideration of the "*Assistant Engineer*," who may also, *to a certain extent*, have to perform the duties of contractor's agent, which will always be the case when the works of a line are sub-divided into numerous small contracts, a circumstance now of no rare occurrence; and in this case the engineer will find his duties and responsibilities doubly onerous. Reference to the extracts made from a pocket section will explain, fully it is hoped, the nature of the remarks required with regard to the contract works; their practical application will be more fully explained in the course of the following pages.

7. The contractor is supplied with a copy of the contract section of the intended line of railway, or any portion of it, the performance of the works on which is entrusted to his execution, and if the levels are set out by his agents, the engineer has but to check them, a simple matter merely demanding correct levelling; but he may have to set out the bed moulds, which should be done in the following manner:—take Fig. 5 for a cutting to be worked from both ends. At stump, 2 miles 27 chains, we are to have for formation 176.41 above datum, and the height of surface is 174.05; plant the level at a convenient point, and direct the levelling staff to be held on the level peg at 174.05, and read off, say 7.00; but 176.41 — 174.05 = 2.36 for height of embankment, and 7.00 — 2.36 = 4.64; now if the staff be raised until we read through the telescope 4.64, it is very evident that the foot of the staff will be held at 2.36 above the surface, or at 176.41 above datum, or formation height; next, direct the staff to be moved along the nick or centre line, and towards the cutting, until we read off with the level 4.64 again, we shall then have found along the nick a point exactly level with the intended formation height at 176.41; but our

gradient is 1 in 78, or .846 per chain; the formation therefore at the point sought will be lower than 176.41 by 1 in 78, ac-

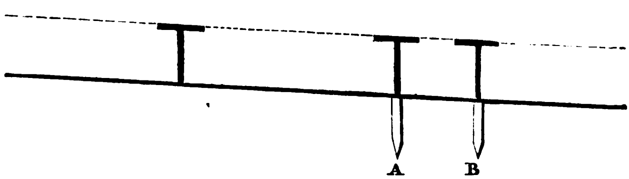
FIG. 5.



cording to the distance from 176.41; let this distance be half a chain, the formation height will then be $176.41 - \frac{846}{2} = 175.99$,

or .42 lower; and if we add this .42 to 4.64, we shall have 5.06; move the staff nearer until with the level this depth 5.06 be read off, when we shall have the desired point; for if when we first read 4.64 the foot was at formation height, as I hope I have made evident, by adding to it .42, and reading off 5.06, we have a point .42 nearer to datum at half a chain distant, and therefore parallel with the incline; and this point found, drive in a stake about 3 in. diameter, until on reading off the staff we have 5.06, and another at 176.41, until we have 4.64, and we shall have two stakes at the required formation height half a chain apart, and by boning from these two heights any tolerable excavator can direct the formation of the bottom of his cutting until fresh

FIG. 6.

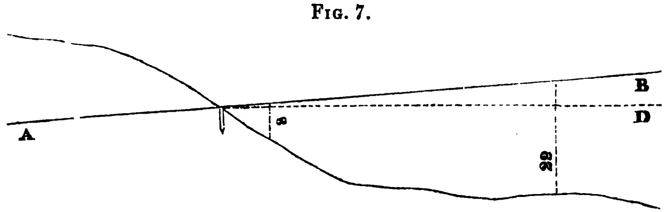


levels are given. Boning is performed with boning rods, which exactly resemble T squares, in the following manner:—let A and B, Fig. 6, be two stakes driven to a certain depth, and according to a given inclination; if on both of these stakes boning rods, of exactly equal length, be held perfectly upright, it is plain that the tops of these will be parallel to the incline, and if a third rod be carried along the intended slope, the top of it will be in line with the top of the other two, if the incline be correct; if it is above there will be more to cut away, and if it is below the excavation will have been made too deep; this method is certainly but approximate, but quite sufficient to guide the excavators for a time. As another example of setting out the bed moulds, we will take the other end of the cutting Fig. 5. At formation 165.60 we have the surface height of 161.80, and therefore a bank of 3.80, plant the level, and then the staff on the level peg, and read off, say 9.50; but 9.50 — 3.80 = 5.70, and if the staff be held up until such depth be read off, then again will the foot of it be at the formation height at this point; move the staff along the centre line until this 5.70 be again read

off, and we shall have a point level with the intended height of embankment; but the gradient here being 1 in 100, the new point sought must be higher in that proportion, as we are now rising, and the distance is 52 ft.; for this distance the rise will be .52, and as we are *rising*, be it remembered, we must deduct .52 from 5.70, when we shall have 4.18; by moving the staff along the nick until from the level we read off 4.18, we shall find the new point for formation, at which drive in a stake. Under no circumstances should this part of the work ever be considered as completed until carefully checked, which should be done by carrying on the levels to the nearest P.P., or permanent post.

8. The incline for the cutting being given, will be, however, but an indifferently approximate guide for the height of an embankment, particularly if of clay and tipped in dry sum-

FIG. 7.



mer weather, for under such circumstances, such an embankment may be expected to settle one-fifth of the height at which it is first formed; let Fig. 7 be a sketch of a cutting and an embankment, in which suppose A B the inclined plane, and the required formation height at B C to be 22 ft.; if the embankment be formed at once to this height, and the above mentioned settlement before perfect consolidation takes place, and it will not be much less, the general height will be something like A D, and will require reforming; it is therefore absolutely necessary to keep the bank high in proportion to the expected settlement, whatever may be the material of which the bank is formed, and a near approximation of the depression may be very easily ascertained a few weeks after the tipping has commenced, due allowance being made for extremes of weather. At 1 chain from the cutting we have embankment height of 8 ft.; as soon as the tip is formed beyond this point, ascertain the height by levelling;

a few weeks after, the depression from the weight of the earth and that of the loaded waggons may be ascertained by levelling again, when an approximate ratio of settlement will be determined, by which the formation of the embankment may be directed.

9. Viaducts and bridges are works which require the greatest accuracy as regards levels, and an error of this description is truly unpardonable, as attention and care are all that are required to carry the construction to the proper height; settlement in the masonry will of course take place, but unless the work is very bad, or the foundation vicious, the difference of level occasioned by this settlement will be immaterial: by attending to the following advice the heights of the crowns of the arches will be found to be perfectly accurate. Fig. 8 is a sketch of a section of a viaduct; A B is the gradient of 1 in 100, or .66 per chain; the span of the arches is 35 ft., the rise is 13 ft., and the thickness of the voussoirs, *Anglicé* arch stones, is 2 ft.; the piers, including the springers, must all be built up to 13 + 2 below formation, that the line under the springers may be parallel to formation. At A we have formation height 340.00, surface height 345.00, or a cutting of 5 ft.; near this we have a permanent post, or P.P. 343.59, or 3.59 above formation at A; plant the level and let the staff be held on the P.P., read off, say 5.25; send the staff on to A, or to *b*, which will make the work much shorter, and this point may be pretty nearly ascertained by the eye; supposing the staff therefore at or near this latter point, read off, say 8.00; 8.00 — 5.95 = 2.75 fall, and 343.59 — 2.75 = 340.84, or .84 higher than 340.00, and also, therefore, .84 higher than a point level with the required formation; now by moving the staff lower down, so that 8.84 be read off, we shall have a point level with formation at A, for 8.84 — 5.25 = 3.59 fall, and 343.59 — 3.59 = 340.00. Now measure the distance from stump 340.00 to the point where the staff was last held, and say it is 15 ft.; the inclination for this distance being .15 rise, the required height for formation will be 340.15; but the height of permanent post is 343.59 — 340.15 = 3.44, and when the staff is held on the P.P., we read from the level 5.25; add to this 3.44, when we get 8.69. Now drive in a stout stake, iron hooped, at the said distance, until the staff being placed upon it we read off 8.69, and it will be at the required height, for 8.69

— 5.25 = 3.44 fall, and 343.59 — 3.44 × 340.15. It has been already observed, that a line drawn along the tops of the piers and abutments under the springers must be 15 ft. below formation height; now it will not be sufficient to deduct this 15.00 from 340.15, giving 325.15, and drive in a stump at that height, because we cannot do so vertically under *b*, and at *c* an allowance must be made for the inclination of the gradient corresponding to distance. But by levelling from *b* downwards to *c*, we can find the height 325.15, which will be level with a point 15.00 below *b*; measure the distance from A to *c*, call it 30 ft., the inclination for which being .30 we shall have 340.30 for formation at this point, and 340.30 — 15.00 = 325.30, to which height drive in a stake as before, and then check by levelling back to P.P. 343.59, which height exactly we shall get if the work has been done correctly. From the appearance of Fig. 8 the reader may be led to think that the above mentioned stakes are driven on the centre nick, but as in this position the excavators would dig them up, they are driven in some 15 ft. on one side; in rock or sound soil these bed moulds are little liable to disturbance, but they are not so safe in a loose ground, and it is always better occasionally to check their heights. If at the other side B of the viaduct the ground was similarly high, we should have but to repeat a set of levelling operations analogous to the last, to get the lines A B and *c d*, but being in embankment this cannot be done, and we must employ another method; the remarks required with regard to the depths of foundations, &c., will be noticed hereafter; we will suppose that at abutment C, and pier D, the masons have reached the heights marked by the dotted lines, we must first ascertain the formation heights at those points, and they are 341.66 and 342.45, and these minus 15.00 will give 326.66 and 327.45 for the heights at the springers. By levelling from a P.P. we find that the height of the abutment at C is 290.05; 327.45 — 290.05 = 37.40, or the height below springers to which the masons have reached, that is that they have 37.40 ft. of masonry to put on to reach springing height, and this height, 37.40 should be entered in feet and inches by the engineer on the foreman's or sub-contractor's book, and a similar memorandum with the date should be entered on his section. At pier D the

height of masonry is ascertained by levelling to be 277.76; and 326.66 — 277.76 = 48.90, the depth at D below springing, and this depth should be similarly entered; and in both cases a crow's foot mark /|\ should be made on the face of the masonry where the levelling staff has been held, that it may be found at any future period. When the piers have reached within a few feet of their due height, it is well again to take the levels, as by then giving the height to be added the masons or bricklayers, but of course more particularly the former, can regulate to a nicety the depth of their courses, and some allowance will have been made for settlements.

10. As soon as the foundations have been excavated to the depth required, the level to the bottom should be ascertained, and entered on the section book as so much below the springing, and this depth should at an early opportunity be transferred to the drawing. On no account, either in viaducts, bridges, retaining walls, or other constructions, should this precaution be neglected, as the depths can then at any time be ascertained for measuring up.

CHAPTER II.

Earthwork.

11. Amongst the many important works connected with the construction of a railway, it is doubtful whether any require more attention, experience, and knowledge than the earthworks of deep excavations, and the formation of heavy embankments. Where, to the unaccustomed eye all appears confusion, in a well regulated cutting, the numerous gangs of excavators move in a confined space with the regularity of well ordered machinery; and those having charge of a heavy work of this description will speedily experience the paramount necessity of strict attention to a correct division of labor, and a serious investigation of the most applicable methods to particular circumstances, as well as a suitable disposition of the means employed in the shape of "the plant," a descriptive account of which to a reader can produce little more than a chaos of confused fancies; one hour's attention to the proceedings and details of work in an excavation would be far more beneficial. There are, however, a few subjects connected with cases of common occurrence of which an investigation may be useful to the *inexperienced*, and which will be attempted in this chapter, the writer regretting earnestly the little assistance he can derive from works on this subject.

12. The first operation, as soon as the widths have been set out, is the erection of the fencing, consisting generally of "posts, railing, and prickposts," the latter planted midway between the posts, and well nailed to the rails; the assistant engineer will examine this work as soon as set up, and see that the posts are firmly fixed and sufficiently deep in the ground; also that the ends of the rails go right through the posts, that

they are fitted, and the whole firm and tight; where this is not the case, the fencing is likely to be levelled to the ground by the "soil" thrown up against it.

13. In "stripping the soil" from the top of cuttings and seats of embankments, it is customary to take it off "spade deep;" it should be piled up along the "Bench," between the intended edge of the cutting and the railings, the grass being laid lowermost; where the bench is 10 ft. wide, a path of about 1′ 6″ should be left along the top of the cutting for the traffic of the men, and by which also the weight of the soil does not bear immediately on the edge of the cutting.

14. Where the top of the cutting is flat, and particularly of a wet nature, as soon as the soil is taken off, trenches about 1 ft. deep should be cut along the lowermost levels, for the purpose of draining off the water to the nearest water courses; this will be found to dry the earth to be excavated, and render it better fitted for the formation of embankments.

15. The determination of slopes for earthwork is one of the most uncertain subjects the engineer has to contend with, if he be anxious to reduce as much as possible the quantity of excavation, and that of land to be purchased, both formidable items of expense; but this reduction is attended with one great danger, namely, a "slip" which will often for a considerable length occasion a double and treble quantity of excavation, and the purchase of a corresponding quantity of land, which in these cases, from the avaricious rapacity of many landowners, becomes enhanced to four and five times its real value; the greatest caution, and the most careful investigation of the nature of the earth to be excavated as far as this can be done, and also of the local circumstances which may increase or diminish the danger of a slip, become absolutely necessary. The slopes of cuttings in gravel will stand at almost any depth at 1½ to 1, and at depths of 10 ft. and 15 ft. at 1 to 1; chalk is more uncertain; in solid rocky masses it will stand perpendicular; friable, it may require slopes of 1 to 1; shale will stand at ¼ to 1, if the stratification be horizontal and dry, but when wet and soapy, there will be great uncertainty; clay however, is by far the most uncertain and treacherous earth to be met with in excavations; we have known it for many months to stand perpendicular for

a depth of 40 ft., and suddenly slip off, determining a slope of 3 to 1; there is no doubt that one of the most dangerous practices of excavators is to allow a gullet of this depth and nature to stand for a great length of time without lightening the sides, nor should it under any circumstance be allowed. A thin bed of clay will very often occasion the slip of material of a better nature, but this may be walled up, and where stone is abundant, it should be done, immediately there is any sign of motion making itself perceptible by cracks at the top of the cutting; there should be no hesitation in such a case, nor fear of the word "expense," where £20 or £30 may save £100. A dry

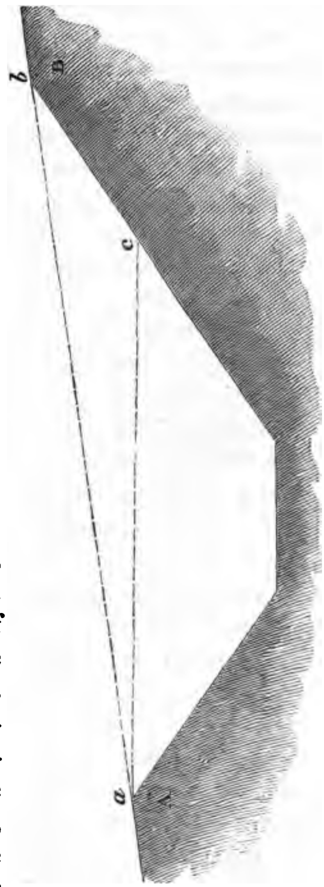
Fig. 9.

rubble wall, built of the largest stone conveniently attainable, will be found the best remedy, both as regards efficiency and economy; *see* Fig. 9. When a slip has once fully declared itself, there is little left but to submit to the circumstance, and to form the slope to the extent determined by the slip, except, indeed, in the case of buildings, or gardens, &c., when we must have recourse to retaining walls and long counterforts with a good system of drainage, which will always be found indispensible; so much so, that no good results can be expected from the best built and thickest walls without it.

16. It is more particularly in cuttings in sidelong ground that slips occur, and this always on the higher side; and we are led by this circumstance to think, that in excavations where the nature of the earth is unfavourable to the stability of the usual slope, 1½ to 1, it would be far better to make the latter steeper on one side, and depress it in a corresponding ratio on the other; the earthwork would be increased on one side, nor would the diminution on the other counterbalance this excess,

but it would not be so great; in Fig. 10, the weight on slope A is diminished, in proportion to the sine of the angle *b a c*, whilst on side B, it is increased in that proportion, the fricton or source of support being also decreased on the side B, in the same proportion, on account of the slip, and increased at side, A; independently of this, the lower side, A, is far more efficiently drained. This would assuredly lead us to the opinion, that the batters should not be alike under such unlike circumstances; nevertheless, it is usual to make the slopes alike; notwithstanding this practice, we should not hesitate in making an experiment contrary to it, in cases where slips might be anticipated, and in cuttings of blue clay, and on sidelong ground, at a depth of 25 ft., and even less, they may be constantly expected at slopes at 1½ to 1; rank and reedy vegetation is a pretty sure sign of a future slip, caution may therefore be used accordingly; surface draining, Art. 14, will always be found the most efficient preventative to slips

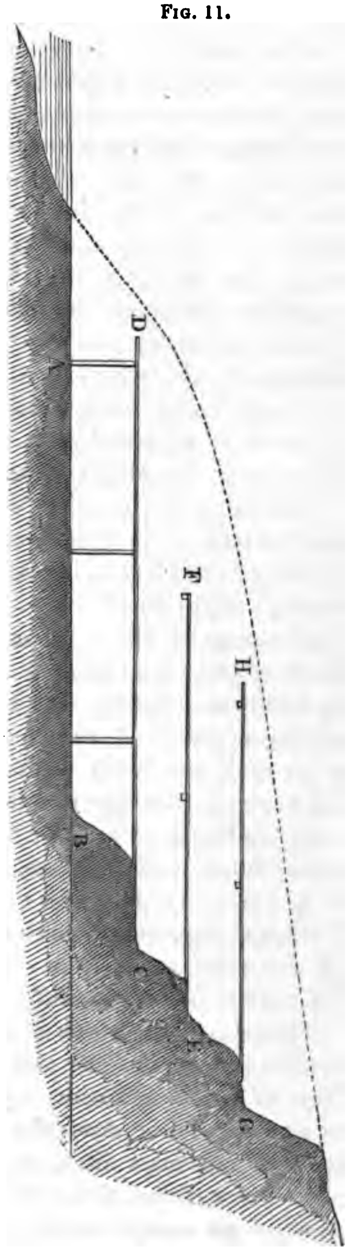
Fig. 10.



which too often occur from this precaution being neglected, and it cannot be too carefully remembered, that against this very serious evil, too much attention cannot be directed. In mountainous districts, the side ditch at the top of a cutting and foot of an embankment requires particular attention, when heavy floods, rushing down the side of a hill will, if not intercepted by a capacious ditch, very soon wash away and destroy the exterior surface of the slope of a cutting, and tear up the foot of an embankment; but of this latter we will speak

further on; attention should also be given to the bottom of the ditch at the top of an excavation, being at a lower level than the edge of a cutting. Another earth, or rather mixture of earths, requiring great precautions, is a diluvium, consisting of large boulders of rocks, clay, sand, &c., where the rock being without bedding, falls in as soon as laid bare, and by its great weight determines the fall of large masses; but against this there is no remedy. One of the most fruitful sources of slips, after the completion of works, as well as during construction, is from springs and soaks rising in the sides of a cutting; these, though acting more slowly, are as certain agents of destruction as gunpowder; the water springing from these must be carried off during the excavation of the cutting, by means of wooden troughs, where more simple means are ineffectual; and, as permanent work, a good brick or stone drain must be run down the slope into the side drain at the foot of the cutting, and the efficiency of the latter will depend upon their soundness and capacity.

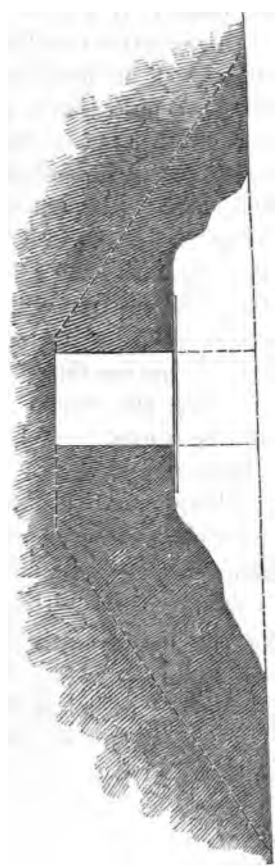
Fig. 11.



17. At the commencement of an excavation, the

earth is removed by means of wheelbarrows to the seat of the embankment; but as soon as a gullet is formed, waggons are introduced, and rails are laid to facilitate the traffic; this gullet is about 15 ft. wide, and the sides kept perpendicular, and, as the depth of the cutting increases, the number of excavators is increased by making fresh "lifts." The sketch, Fig. 11, will perhaps assist in explaining; the empty waggons would stand along plane A B; those nearest to B would be filled by excavators working against the face B; the waggons nearest to A would be filled from the face C, the earth there excavated being wheeled in barrows along planks C D, and tipped into the waggons, and the waggons midway between A and B would be filled from E, from which the stuff would be wheeled along planks E F; in cuttings of 30 ft. deep, we have seen excavators thus working four lifts, six excavators being at work on each face. The excavations on the sides of the gullet should be carried on at the same time, as soon at least as the gullet has made some progress, by similar means, and in a like way—that is, by gangs of men working above each other, wheeling along planks, and tipping into the waggons below, Fig. 12; the planks are supported on uprights, or on transverse baulks. It is by having as great a number as possible of excavators, but not

FIG. 12.



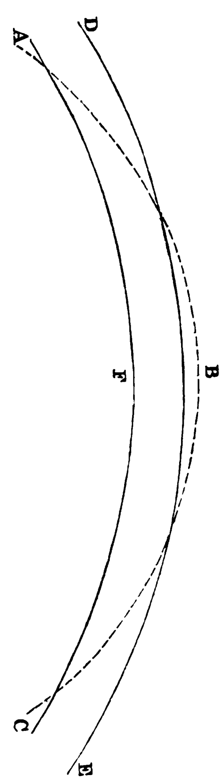
enough to embarass each other, with a proportionate number of wheelers, and relays of wheelers, drivers, horses, and men at the tip, that a cutting and embankment progress rapidly and satisfactorily; and it is in so ordering the proportions of men to each task, as well as the disposition of the materials forming "the plant," that none shall be for a moment idle, and that a free passage for the going and coming of the wheelers be at all times kept open, that knowledge and experience on this subject are displayed, and which can only be acquired by strict attention and experience. In order to relieve the horses from as much labor as possible, it is proper to give a greater inclination to the plane A B, Fig. 11, as the excavation and tipping advance, consequently, receding from each other, in order that by the sole effect of gravity, the waggons may obtain the greatest possible run towards the tip; it will therefore at once be seen how much, even at this stage of the work, depends on a good laying and maintenance of the way; for if it be not kept in tolerable order, the waggons are continually getting off the rails, thereby occasioning a delay of serious import by delaying those behind it, until it be got into its place again, to do which, with a heavy load of earth, will take a considerable time. These remarks hold in all earthworks, either of railways, docks, harbours, &c. By paying due notice to these details, the engineer when inspecting the works, may judge pretty readily of the progress of the works.

18. With regard to the proportions of men required for "getting, filling, and wheeling," or of waggons, horses, and drivers, local circumstances can be the only guides; if we were to ascertain these proportions by $\frac{t}{t'}$, where t represents the time of "getting," that is, excavating, and t' the time of filling or loading, the proportions would so far be ascertained; but our excavators, besides picking, have recourse to what is termed "falling," that is, breaking down a mass of one or two cubic yards often in a few minutes, by driving in short piles shod with iron, and pouring in water until a mass falls to the bottom of the lift, where it is broken up by picks, and the quantities thus fallen are continually increasing as the depth of the face deepens; this would necessitate continued fresh calculations, which would be but indifferent approximations; the number required of

wheelers would be under the same unfavourable circumstances for calculation; it is therefore usual to judge of the proportions required on the spot as the work proceeds, which will, in this case, be found better adapted to practice than calculations made without sufficient data.

19. Where the centre line of an excavation is straight there is little risk of the excavators cutting into, and thereby irremediably deteriorating the slopes of a cutting; first, because they know very nearly (to a few inches) where their centres are, and by multiplying the depth by the ratio of slope they can keep themselves straight, the more easily that they seldom work to their formation depth until the levels are given, because if they go too deep, not only they are minus in pay the extra quantity of excavation, but they have also, at their own cost, to replace ballast to fill up the extra depth; we would not, however, recommend an engineer to depend too much on this, as excavators will often make strange blunders; we have known an old excavator, of fifteen years standing, with three correct levels within a chain on each side of him, make an error of 3 ft.; we would, therefore, recommend the assistant-engineer to keep a close look out after these matters under any circumstance. Where the centre of an excavation is a curve, in order to ease the running of the waggons, it is customary to flatten the curve of the gullet as much as possible, and here the excavators are by no means unlikely to cut into the slopes, unless their centres are often given to them; in Fig. 13, let A B C be the nick; the excavators will flatten the curve of the gullet by running it at D E, and they are consequently likely to cut into the slopes at A, F, C, unless the ganger is made aware of the position of his centres. At the same time continual setting out of the

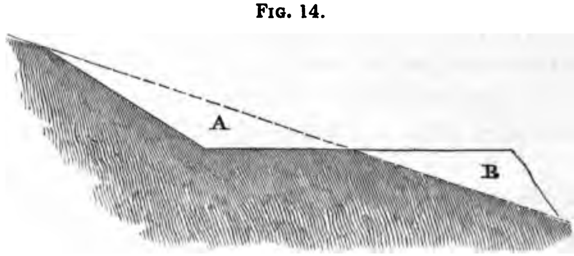
Fig. 13.



curves where they are numerous is a work absorbing much time; we, therefore, recommend the practice of driving in stumps at each side of the curve stumps, after their being once found in the gullet, and noting the distances; these side stumps, being less liable to disturbance than the centre stumps, serve as guides to set off the centre line sufficiently near, until the time comes when the centres are required for the permanent way.

20. It is by no means an uncommon occurrence that a cutting is so situated, either that the length of lead is too great, or which is the same thing, too expensive; or a heavy cutting may be what is termed locked up, that is, there may be no road to lead the excavated earth to a tip, either from other cuttings being between it and the nearest embankment, or a viaduct or bridge may require to be built before a road can be got ready for the waggons to run; under these circumstances the whole, or a part, must be "led to spoil," that is, some hollow must be filled up, or some bank formed, upon land unconnected with the railway; a hollow to be filled up would, of course, be preferred, both for the greater convenience of tipping, as well as because it would afterwards be easier to lay the soil on it, and "make it into land;" when it is necessary to lead excavation to spoil, it is customary to rent the land for a term, two or three years, or to pay compensation for damages; Fig. 14 shows the easiest spoil bank to be formed, the dotted line representing the original surface, the earth having merely to be excavated from A and tipped at B; a large number of men may excavate on the face, and there may be a corresponding number of tips; Fig. 14 repre-

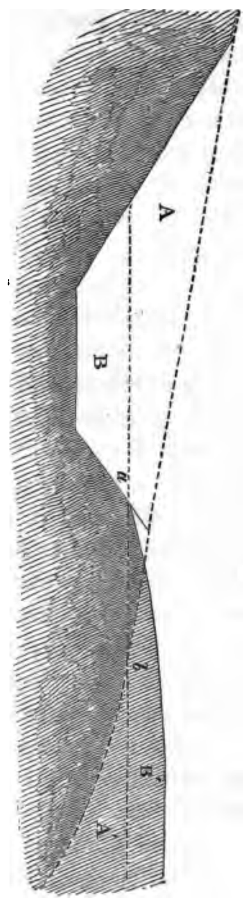
Fig. 14.



sents what would be a more complicated, and expensive case. The upper dotted line as before represents the original surface; at every 15 or 20 yards along the lower ridge of the cutting

gullets are cut a few feet deep, as shown by the lower dots, *a b*, through which waggons in this case may at first be employed, to lead off the portion marked A in excavation and A′ in spoil; the lower portion B of the excavation must be raised by barrows wheeled upon planks and deposited at B′ on A′. Excess of cutting may also be disposed of by widening the nearest embankment, that is instead of making it 30 ft. at top make it 40.

Fig. 15.



21. Another common occurrence is to find an intended embankment placed in a position very similar to that of the above mentioned cutting, that is, either there may be no excavation to form the embankment with, or the embankment may be locked up, or the material may be too distant, and it may be cheaper to purchase land for "side-cutting" from the excavation of which the embankment may be formed entirely, or in part; the Fig. 14 may be a case of this kind, putting B for the embankment, and A for side-cutting; when land is purchased or rented for spoil banks or side-cutting, the soil should be stripped off and carefully preserved, as it is ultimately to be relaid on the top of the spoil bank, or bottom of the side-cutting; in either of these cases, as indeed in all other matters, due judgment should, of course, be exercised as to what excavation should go to spoil, or what embankment should be formed from side-cutting; also as to the side of either of these auxiliary resources, but *ceteris paribus* the nearest will be the best.

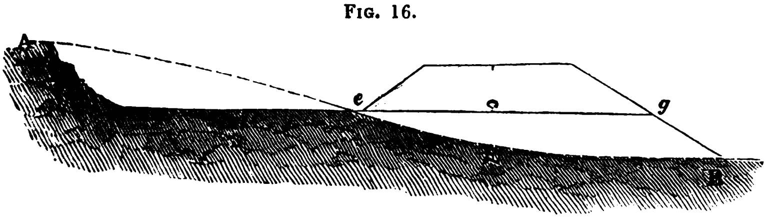
22. The next most important feature in earthworks, and intimately connected with the last, is the formation of embankments, and when these are of great depth, and to be constructed

with unfavourable materials, and under unpropitious circumstances, they require the serious attention of the engineer, and this not only as regards the embankments themselves, but also the masonry and brickwork on the line, often, as well as other works and buildings at a considerable distance. The best materials for the formation of embankments are gravel and sand, both from the facilities they offer for drainage, and their more rapid final consolidation; *soft* shaly earths are unfavorable, but if hard and dry they form good embankments, and settle well at slopes of 1 to 1; vegetable earths, or what is termed soil, must be entirely rejected for the embankment from their being so easily converted into soft mud; landowners, however, are always ready to carry these away, but care should be taken to preserve a fully sufficient quantity for soiling slopes, as when a good depth of soil has once produced a strong vegetation, it forms one of the best safeguards to slopes; clays mixed with a quantity of stones are by no means a bad material, and, if dry, will form a sound embankment, though rather long in consolidating; wet clay is as bad if not worse than peat; it should never be allowed to be used, under any circumstance whatever; a few waggons of wet clay tipped in a deep embankment will do more mischief by its slipping and saturating all other materials laid on it, than one, or even two thousand of good stuff will rectify, besides becoming for many years a continual source of settlement, and perhaps of danger on that portion of the line; where the less favourable materials must be employed for forming embankments, it is as well to make an exception to the general rule, of forming at once an embankment to its full height and width, and to leave a few feet in height to be raised up with drier materials, *if conveniently at hand;* isolated masses of this description are often found in excavations otherwise of very inferior materials, which may be successfully employed for this purpose, after having, however, the positive assurance that enough remains for ballast. This is, perhaps, all that we can generally effect as regards selection of material, without involving a company into great expense, because the embankment must almost always be formed of the materials from the nearest cutting.

23. With regard to the precautions necessary to be observed

in the formation of embankments, we must be guided by a careful judgment of causes and effects, which are necessarily continually varying with local circumstances; there are, however, a few cases of common occurrence of which it may not be unserviceable to say a few words. To obtain a thorough consolidation, and a complete unison of the mass, as well as to secure, as nearly as it can be done, uniformity and regularity of inclination in the side slopes, an embankment should, from the first, be formed to its full width and height, care being taken to make allowance for shrinkage and settlement from the gradual combination of particles into a solid mass, of this we have already spoken above; at Art. 22 has been instanced a case where departure from this general rule is admissible, and this beneficially. Another case may be the same as or analogous to the following;—we have an embankment to form which will require 80,000 cubic yards, and this embankment is at the tail of a cutting containing only 50,000; moreover, the next excavation beyond is required for other embankments, or it is at a great distance, which would make the lead a considerable item of expense, or it may be locked up from the embankment we are now anxious to form; it is evident we must get 30,300 cubic yards from side-cutting; if we are on sidelong ground, we can easily obtain this extra quantity from the upper side of the hill, and this very rapidly, as we can employ a considerable number of men upon a broad face; let Fig. 16 represent a case of this

FIG. 16.

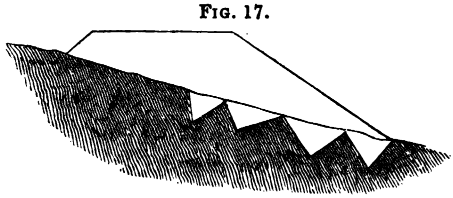


kind, A B being the original surface; set out the foot of the slope towards A, and from that foot excavate into the side of the hill, and form with it the lower portion, dotted off, of the embankment until the 30,000 deficiency is made up, taking care that this base of the embankment is formed of the required width for the depth and with the proper slope; if the depth of the embankment is here of 20 ft., and the height $c\ d$ is 8, that is 12 below

formation, we shall have the following calculation; base 30 + 12 × 2 (ratio of slope) = 54, and twice the ratio of slope will give 78 for the width required along *e g*; we shall not always find the side-cutting so convenient as this; rising ground may be at a considerable distance, which would, therefore, much increase the expense, and it may, in many cases, be better to cut a trench of some breadth a few yards from the foot of the embankment, and wheel the stuff up to the seat; all cases, however, connected with side-cutting and spoil banks vary so much that circumstances alone can direct the best modes of proceeding.

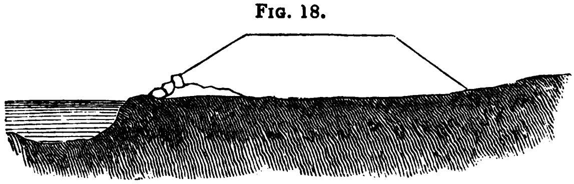
24. In forming an embankment in sidelong ground, steps should be cut in the seat of the embankment which should dip at right angles to the batter, and where the ground dips round from the sides to the front in the direction of the tip, these steps should be brought round also. Fig. 17 will show how

Fig. 17.



very much the earth would tend to slip under pressure along the natural surface. Where this is neglected, there will not fail to be continual slips, and of a serious nature, from the embankment never becoming firmly seated. Where a bank runs along the edge of a river, stream, pond, &c., the foot of the slope should be pitched with large stones, well bedded at right angles to the batter, and these should be backed up with a foot or two of clay paddle, Fig. 18. Great care should be observed in carrying

Fig. 18.

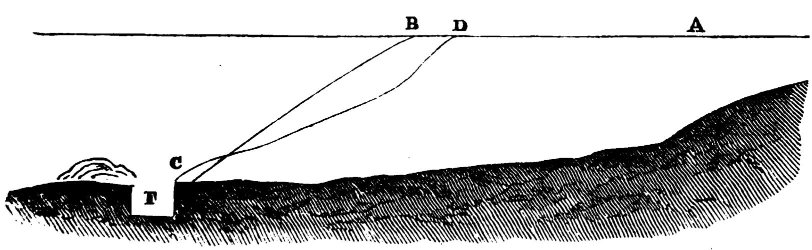


ing an embankment over a bridge, or up to the abutment of a viaduct, or there will be considerable risk that the weight of

earth will spring up an arch, or overset the abutment; in no case should this be done until the mortar has become perfectly set, and until the abutment has been well punned up, when the greater mass will deaden the effect of the weight of the earth tipped over. The greatest care will be necessary in carrying an embankment over or near subterraneous works; unless these be at a very great depth, the embankment should be formed in successive layers until some height is obtained, and, during the progress of the embankment, the underground works should be constantly visited, and strengthened where required; an accident under these circumstances occurring in the subterraneous constructions, would be made a source of heavy expense to the company; in passing over mining districts, it is well to make arrangements for giving extra support to the galleries unless at a great depth, and where the beds have not been worked, to allow compensation for certain portions being left unworked. In carrying an embankment along a retaining wall, attention should be given that the latter be well punned up before the earth is allowed to be tipped along the back of it, and the same remark will hold as regards long and deep wing walls, which, if this precaution be neglected, are very likely to be overturned, or at least disfigured, by being forced out of their intended form.

25. Either from material in too wet a state having been allowed to be tipped, or from water having accumulated on the seat, it most unfortunately, as well as unnecessarily,

Fig. 19.



happens, that the tip will slip not only transversely, but also in length. At Fig. 19, the line, *A B C*, shows the tip, as it would have been but for the circumstances just mentioned,

instead of which it assumed the form *A D C* in every direction, nor could the work of 15 days make any change; at last the trench, *F*, was cut across the seat of the embankment, and two more cut along the sides, the first determined a more vertical direction for the tip, and the latter trenches drained the seat; by these means the slopes were brought back to a proper state.

26. An embankment will generally be formed along the side of a hill, or in a valley, always at a lower level than the approximate land on one side or the other, and, consequently, it will be converted into a dam, which will pen up the rain waters, which, after heavy falls of rain or rapid thaws, will accumulate from the sides of the highest grounds down to the embankment, and greatly endanger the embankment, unless sufficient outlets have been provided. Where streams run under the embankment through culverts, but little more will be required to carry off freshets; but where this is not the case, we must increase the number or diameter of the drains, which would, under any circumstance, be required, under an embankment of any length, particularly if the seat give indications of water, and for the position of which the lowest natural levels will be selected; on a wet seat no embankment will ever properly settle without assuming a breadth of slope never originally contemplated.

27. According to the length of lead, the quantities to be excavated, the speed required, and the width of base, the number of tips will be greater or less. Three is a usual number, but with more than four the number of waggons and horses are apt to get confused, and thus cause delays rather than speed, though the number and efficiency of the men at the tip, as well as the dexterity of the drivers, will determine much of this; whatever number of tips there may be, care should be taken that the outermost be kept the foremost; the inner tips falling between tend to force a firmer consolidation. The various circumstances connected with earthworks render a minutely accurate forming of such work very uncertain, principally for the two following reasons:—it is impossible, practically, to ascertain the exact nature of an excavation through its entire length, so that we can only take an average, and in a district where engineering works have been unknown, the value of labour will

be for a long time uncertain, although the neighbouring population will not fail to demand the full current wages of practised hands. The two following tables will, however, be found approximations of a very close character, having been deduced from practice and close observations. There are two sections—the first for rock, and the second for earths; the values of materials have been reduced in a similar manner to the values of labour, because they will continually be found to vary with the last; the number of working hours being considered 10, it will only be necessary to ascertain the wages, when the following proportion can be obtained:—as 10 hours: the sum of wages per day in pence:: the constant: the detailed prices for each kind of labour per cubic yard; or, as 10 hours: wages per day in pence:: the total at the foot of each column: the sum in pence for each kind of excavation.

First Section.—Rocks.

	I. CLASS.	II. CLASS.		III. CLASS.	
	Primary and generally Transition Rocks. Granitic and Porphyritic; Basalts and Greenstones; hard and heavy, and in large and unstratified masses.	Secondary and occasionally Transition Rocks. Limestones, Sandstones, and Oolitic Rocks; in large and compact masses.		Secondary and Tertiary Rocks Schistous and Shaly Rocks, in thinner strata, and of looser character than the II. Class.	
Denomination of Labour or Material.		With Powder.	Without Powder.	With Powder.	Without Powder.
	Value in Hours of Excavator.	Value in Hours of Excavator.		Value in Hours of Excavator.	
Drilling . . .	4.14	1.38	. . .	1.25	
Powder . . .	1.84	1.38	. . .	1.25	
Getting . . .	0.69	0.58	0.64	0.46	0.58
Filling . . .	0.69	0.69	0.69	0.69	0.69
Tipping . . .	0.12	0.12	0.12	0.12	0.12
Grease and Repairs of Waggons .	0.29	0.29	0.23	0.23	0.23
Iron and Steel . .	0.46	0.41	0.35	0.41	0.12
Repairs of Roads .	0.12	0.12	0.12	0.12	0.12
Lead of 100 Yards .	0.23	0.23	0.23	0.23	0.23
	8.58	5.20	2.38	4.76	2.09

Second Section.—Earths.

Denomination of Labour or Material.	I. CLASS. Hard dense Clays and Marls.	II. CLASS. Loams and lighter Clays and Marls.	III. CLASS. Gravels and Loose Stuffs.	IV. CLASS. Sand.
Getting	0.35	0.46	0.23	0.23
Breaking up	0.46			0.00
Filling	0.81	0.69	0.64	0.58
Tipping	0.12	0.12	0.12	0.12
Grease and Repairs of Waggons	0.23	0.18	0.23	0.23
Iron and Steel	0.29	0.18	0.12	0.06
Repairs of Roads	0.12	0.12	0.12	0.12
Lead 100 Yards	0.23	0.23	0.23	0.23
	2.61	1.98	1.69	1.57

CHAPTER III.

Permanent Way ; Formation and Drains ; Ballasting ; Levels of Rails.

28. CONNECTED with the permanent way, the four subjects in the heading of this chapter, come into primary and most important consideration; the railways now constructed vary, for the width of formation, from 28 to 31 ft. generally; and in order to effect a perfect drainage of this formation, it is necessary that the centre of the line should be higher than the sides, and this increase of height varies from 3 to 6 inches; the heavy traffic occasioned by earthworks will render it very difficult to maintain this ridge, if the seat of the ballasting is at once formed to this height, and as an efficient drainage is indispensable, it is better to leave a small depth of excess of excavation and to make the formation to its proper levels, immediately before the ballast is laid; this subject will be found to deserve more serious attention than might at first sight be afforded to it, for if this "formation" be not constructed so as to effect thoroughly the passage of waters into the "sidings," or side drains, whatever trouble may be devoted to the maintenance of the permanent way, will be comparatively lost, as well as the expense attending it, and this latter very serious consideration will be exactly in the proportion of neglect with which the permanent way is first constructed; the engineer should therefore give strict injunctions to his inspectors to attend carefully to this, and should direct his personal attention to it as much as possible. Sub-contractors, to whom the earthworks are entrusted, will be generally found perfectly indifferent on this subject, as when once the ballasting is laid, there are no means of detecting slovenly work without taking it up again.

29. Sidings, or side-drains, form the next subject of consideration. In a hard solid substance, or in rock, and more especially where great economy is at first to be of paramount importance, a good ditch may be cut, with slopes battering in the same ratio as the slopes of the cuttings, but where the stratification is of a softer nature, where the excavation is deep, if not in rock, or where the slopes are liable to deterioration, from atmospheric effects, from rains, soaks, springs, or from the numerous injuries to which they are constantly liable, it is necessary, in order to preserve a free and uninterrupted passage for the waters and debris which accumulate at the foot of the cutting, that side-drains of rough masonry or brickwork be constructed, and these of sufficient capacity, by depth and width, to answer the purpose intended. In passing through marshy soils, this capacity will require to be increased, often considerably, and transverse covered drains leading from the higher to the lower side of the way, will also be requisite; as, comparatively speaking, these drains have but little strain to resist, they may be constructed at the least possible cost — rough unhewn stones are all that is required, and these not of large scantling; of course, we are not now alluding to drains which are constructed across the formation for carrying off surface water, accumulating in ditches, and penned up, which must be disposed of, often by carrying it over the line to a lower level; specimens of these will be found

Fig. 20.

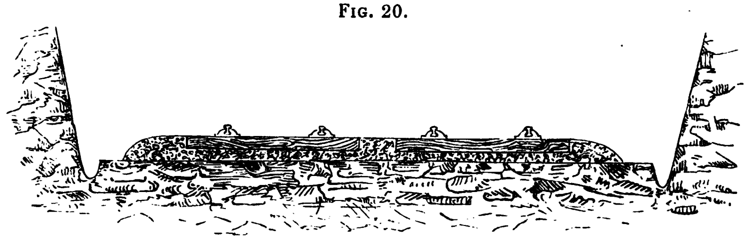
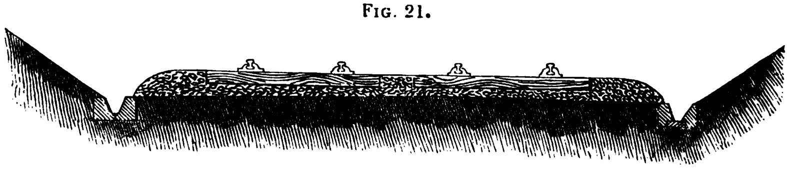


Fig. 21.



amongst the examples of drains and calverts; and Figs. 20, 21, 22, 23, and 24, represent various kinds of permanent ways.

Fig. 22.

Fig. 23.

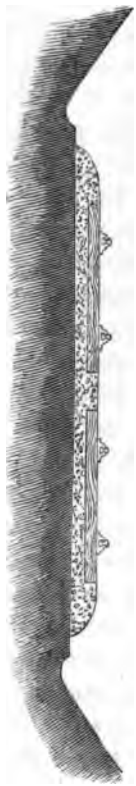
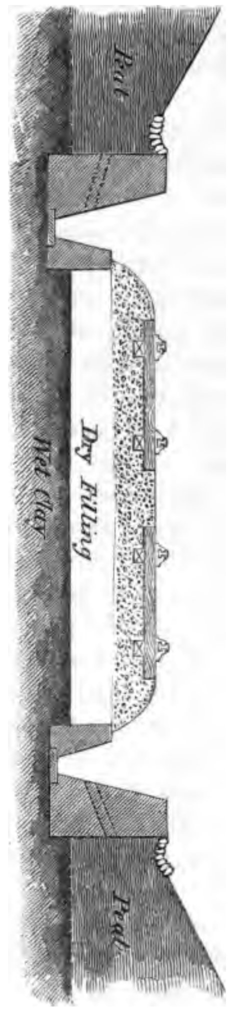


Fig. 24.



30. The formation having been levelled to the degree of convexity required, the next operation is the ballasting, which is to form the foundation for the sleepers, and which must be of such a nature as to allow water to percolate with the greatest

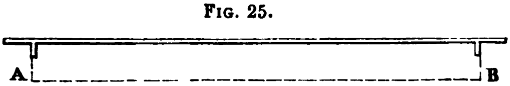
freedom, in order that this foundation be kept perfectly dry, or not only the sleepers will decay, but they, and consequently the rails, will be in considerable state of motion at the passage of every train, from a portion of the ballast being reduced to a soft muddy state. The best ballasting consists of hard broken stone, but it is expensive; good dry gravel forms excellent ballasting, and where found in excavations, should, as much as possible, be preserved for this purpose; sand, mixed with broken stone, is equally good. Where these cannot be obtained, we may be satisfied with good clean cinders, or slag, which also answer the purpose very effectively; where none of these can be obtained, we may use hard shale, well burnt for the upper coating of ballast, though it is rather liable to cake, but much less, however, than burnt clay, which we have seen used for this purpose; even the last may be improved by an admixture of sand before burning. Whether broken stone or gravel be used, care should be taken that all stones larger than an egg be broken up, and more particularly for the following reason: should a large stone be placed under a sleeper, and have an uncertain bearing, or present an angle to the underside of a sleeper, it will act like a pivot for this latter to move upon, and at least injure considerably the stability of the rails at this point, if it does no more. The ballasting will require to be at least 12 in. at the greatest depth; it should be well levelled and well packed, and any means that could be used to force it down to a more solid bed would be a great improvement, as it would tend to lessen the subsidence which ensues from the first few trains passing over the line; the traffic, however, which is necessary for completing the works will tend greatly to effect this.

31. On this first bed of ballasting the sleepers are laid; these are generally of larch fir; they should be sound, free from shakes or signs of decay, straight, and of good form, as also of the scantlings specified by the specification, which are generally 8′ or 9′ × 9″ or 10″ × 5″; besides these, there are the sleepers for the "joint chairs," which should be 12″ wide and squared; these sleepers should be carefully examined and measured, as delivered by the contractor, and all inferior ones rejected. A broad notch or bed is cut on the upper side of the sleeper for

the seat of the chair; and, as one end of the sleeper will often be thicker than the other, in consequence of the timber being unsquared, this stouter end should on curves be placed under the outside rail; attention should be given, that the beds cut for the reception of the chair be of full size to afford a sufficient seat, and also that the bed be perfectly flat; on this seat the chairs are fitted, as soon as the sleepers have been approximatively placed in their places along the line, and the rails placed in the chairs; the plate layers then commence setting out the straight lines and curves with reference to the stumps, and bed moulds set out or checked by the engineer, to which subject we will return presently, and gradually, by means of boning and gauging, which is done by means of a standard, measuring exactly the distance between the rails, the rails are brought to their true position; this being done, holes are driven in the sleepers for the reception of the spikes on one side, at each end of every length of rail, and next on the other side, the greatest care being used to have the guage constantly applied, and the spikes are driven; a piece of felt is often introduced between the chair and the sleeper, but vulcanized india-rubber will be found very superior, the india-rubber occupying a space equal to the seat of the chair, and the spikes being driven through it; the elastic nature of this substance tending materially to soften the shock which the wheels meet with as they successively cross each sleeper, and diminishing the effect of the vertical motion which the spike must experience in a greater or less degree in the sleeper. The position of the sleeper, chair and rail is then permanently fixed, by the operation of what is termed boxing up, which is fixing under each sleeper about an inch, more or less, of a finer description of ballasting consisting of fine gravel or good sand; by these means the rail is fixed permanently and correctly, both as regards the horizontal direction or centre line, and the levels of the gradient. Ballasting should then be filled up to the upper side of the sleeper.

32. The guage commonly used by plate layers is an iron rod, of the shape shown at Fig. 25; the distance between A and

FIG. 25.



B, being the measure from rail to rail, but it meets with so much rough usage, and is so often bent and straightened again, if the men will take so much trouble, that it cannot be depended upon. Fig. 26 shows one of a superior kind, which should be

FIG. 26.

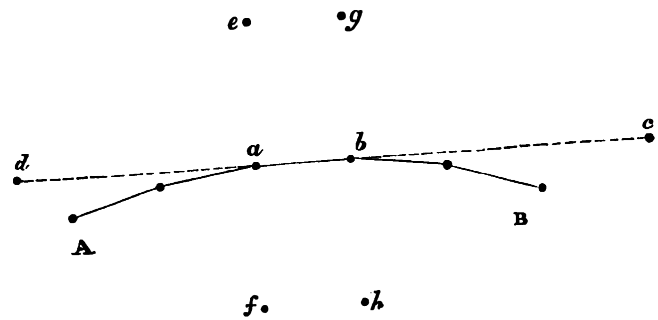
A

made of a piece of hard well seasoned wood, and, if varnished, will be less affected by damp; at A, there is a spirit level, by which the transverse level of the rails may be ascertained; inspectors should be supplied with such a gauge, and with it, check with care the work of the plate layers.

33. At § 19, we have alluded to the centre line having to be set out a second, and often a third and fourth time, in excavations and embankments, and unless the engineer, where he has to do this work, takes proper precautions, he will find it an endless work, or the contractor will most likely commit great errors. By referring to the first part of the "Assistant Engineer's Guide," the reader will find some advice on this subject, and we will here add some further instructions, by following which, the work will be found much lessened, enabling therefore the professional man to attend to other matters requiring his attention. Where the tangents or straight lines are of any length, poles are always set up out of the works, by which, of course, this straight line of centre can always be found; and, by knowing from the section at what distance on this line the curve was commenced, this point may at any time be found also, and the curve set out; but on curves of 50 or 60 chains, or where these are numerous, we have pursued the following plan, by which, at any time, we could find exactly the original site of centre stumps; Fig. 27, will assist the explanation. Let A B be the curve, with the stumps shown by black dots; the straight lines between these are of course chords; take any two of these stumps—say *a b*, produce the line out beyond the edge of the cutting, as at *d c*, where drive in a couple of stumps *likely to remain;* at right angles to this line, and in line with *a*, sight out *e a f*, and drive in *permanent* stumps at each of these also; do the same thing at *g b h;* and make

a note on the section book for reference hereafter; now at any future time, by sighting out these lines with accuracy,

FIG. 27.



we find the exact position of *a* and *b*, by which we may set out the curve; we do this in one or two places generally along a curve; by these means there is no difficulty either in re-setting out or checking; in the outset this may appear rather long and tedious, but where a cutting of 30 ft. or 40 ft. deep is being excavated, and the centres are to be found, it will afford a very ready way at any time to obtain them; this, and the simple method shown at § 19, will prevent all difficulties and loss of time; care must be taken in setting out the permanent centres of an embankment, that we pass through the centres of bridges and culverts; stumps at every chain length must be carefully and firmly driven into the top of the embankment or bottom of the cutting; by these stumps the position of the rails is fixed, and therefore, the straightness of the line where straight, and where otherwise, and the regularity of the curve depend on the position of these stumps.

34. The levels connected with the height of the permanent rails require the utmost nicety in the operation of levelling, for although, except in a few situations, it will be almost impossible, *at first*, to keep the railsat the given heights, the bed-moulds remain, if properly fixed, for two or three years afterwards, for the reference of the plate layers; if the permanent way be properly constructed, and these levels accurately set out, there need not be at any time, after consolidation, any deviation from the correct

height. In cuttings, the bed-moulds,* with very few exceptions, will remain at the heights to which they are driven at first, but not so in embankments on account of the settlement of this latter construction; but even here we shall have the bridges on which the height of rails may be fixed with the utmost accuracy. Having provided sufficient bed-moulds, commence from a P.P., or B.M., of the correct height of which there can be no possible doubt, and level from this to the temporary rails, or any convenient object at a stump or chain's length, and ascertain the difference of level, and, therefore, the height of the second object levelled to with regard to datum, and consequently to formation, as the height we require above datum at this point will be obtained from the section; say, for instance, that the height of the P.P. is 302.46 above datum, and the *difference of level* between this height and that of the *temporary* rail or other object levelled to is 23.10 *lower;* then we shall have 279.36 for the height above datum at this point; now refer to your pocket section, and in doing so be careful of two things:—first, that you do not mistake one chain stump for another, which would occasion *one* great error, and secondly, do not mistake formation for rail height; to practical men these two last hints may appear puerile, but we *do not* profess to write for these; the young practitioner, on the contrary, from the extreme facility with which either of these errors may be committed, is very likely to fall into them. To continue, we have found the height 279.36, and we carefully ascertain that this is at 5 miles 7 chains, where the formation height is 277.06 by the pocket section; but formation is 2.00 below the level of rails at every stump; then $277.06 + 2.00 = 279.06$, which latter is to be rail height at this point; but $279.36 - 279.06 = .30$, therefore, 279.36 is .30 too high, because it is .30 further from datum than 279.06, which is the correct height, and, consequently, we must have the top of our bed-mould .30 lower than 279.36; we trust this is sufficiently plain. Now, let the staff be still at 279.36 read off, *and see that you read the same height as before,* say 4.20; since it is .30 *too high,* if we could read off 4.50, the levelling staff would then be standing on some object at the correct height

* A bed-mould is a stake of about $2' \times 3'' \times 3''$.

of rail, for 4.50 — 4.20 = .30 fall, and 279.36 — .30 = 279.06, which is rail height; we have, therefore, nothing to do but to drive in a bed-mould, until the levelling staff being placed upon it, we read off 4.50, when we shall have rail height at 5 miles 7 chains. We must now continue driving in these bed-moulds at intervals, a certain number of chains apart, *up* or *down* the line. On a level we should have but to plant the level *midway* between the first bed-mould, and the chain stump where the second would have to be driven; read off the staff on the first bed-mould, say 4.50; then driving in a bed-mould at any point along the intended level, until we read off 4.50 again, we should have a second bed-mould level with the first, since 4.50 — 4.50 = 0.00, or no difference of level. But say we are going down the line, and that our gradient is 1 in 150 or .44 per chain; as we are going down we shall have to drive our bed-moulds lower than the last by a height of .44 × the number of chains further on at which the next bed-mould is driven, that is for 1 chain .44 lower, for 2 chains .44 × 2 = .88 lower, 3 chains 44 × 3 =1.32 lower, and so on; setting out the levels along a straight line, it will be sufficient, if the bed-moulds be driven at 4 or 5 chains apart; but on a curve they should not be farther apart than 2 or 3 chains length, and it will be found more likely to keep the work of the plate layers correct, if these heights be driven on one side and the other of the line alternately; supposing that we are now setting out the levels on a straight line and falling gradient, and at 5 chains apart, we should first plant the level about half way, the staff remaining on the bed-mould 279.06; now .44 × 5 = 2.20; then at 5 miles 12 chains rail height will be 2.20 lower than 279.06 or 276.86. Read off the staff, say 4.80, and then let it be taken down to the bed-mould at 5 miles 12 chains; since the rails at this stump should be 2.20 lower than at the former stump, we shall have to add this depth to the last reading of 4.80; and this + 2.20 = 7.00; and the bed-mould must be driven until we read off correctly this second reading; for B.S. 7.00 — F.S. 4.80 = 2.20 fall, and as above, 279.06 — 2.20 = 276.86 from datum. Let us now suppose we are going up the gradient, instead of adding .44 × 5, we should have to deduct it from the reading required on the bed-mould, at 5 chains higher up the line, since this would be

$.44 \times 5 = 2.20$ farther from datum since it is a rise; then having again planted the level midway to obtain this rise, read off the staff on bed-mould 279.06, say 5.43, then $5.43 - 2.20 = 3.23$, which is the reading we shall require at 5 miles 2 chains; and the bed-mould must be driven until we have this reading, when the staff is held upon it; for B.S. 5.43 — F.S. 3.23 = 2.20 rise gradient upon 5 chains, and 279.06 + 2.20 (since we are rising, and, therefore, getting further from datum) = 281.26. On a descending gradient, therefore, the difference of levels for a certain number of chains must be *added* to the back sight; and on a rising gradient this quantity must be *deducted* from the back sight; in the first case, therefore, it is always +, in the second always —. If we have been minute in explaining this, it is because we have once or twice found it rather unintelligible at first to beginners, who are apt in setting out to confuse the datum line with that which corresponds to the axis of the telescope of the level. Having set out two bed-moulds we proceed in the same way if we require a hundred, and we will, therefore, only add the farther recommendation, of planting the instrument about halfway between all the stations; and this more particularly to avoid the error consequent upon any want of adjustment in the level, and further, the most indispensable condition that having set out the last bed-mould required, we must produce the levels on to the nearest B.M. for a check on the work, or we can have no assurance of the accuracy of the levels. On checking up to the B.M., of course the last height obtained must be that recorded on the pocket section for the height of the B.M.; any difference found will be so much error. Proceeding, for ininstance, as before, suppose we have set out 65 chains of levels, then $.44 \times 65 = 28.60$, and if we are descending $279.06 - 28.60 = 250.46$ at 5 miles 72 chains; and on levelling up to the B.M., which suppose 262.50 we must find a rise of 12.04, between the last bed-mould set out, and the B.M., because *all* the levels refer to "Datum" as well as to "formation height," and "rail height," and from the first of which the two latter are originally deduced. In conclusion on this subject, we will add that these bed-moulds should be driven so firmly into the ground that intentional violence will alone disturb them, and that they should be so placed as to be out of the way of horses' feet and waggon wheels.

35. On account of the tendency which carriages have to pursue a straight course when moving along curves, it is necessary to raise the outer rail, in order to counteract this effort; in the following table will be found the minima quantities usually allowed for this; for a full consideration of the subject, we refer the reader to Wood's "*Treatise on Railroads*," Chap. iv, § 15.

Radius of Curve in Chains.	Rise in Inches.
10 = $\frac{1}{8}$ mile.	2.00
20 = $\frac{1}{4}$ "	1.07
30 = $\frac{3}{8}$ "	0.71
40 = $\frac{1}{2}$ "	0.53
60 = $\frac{3}{4}$ "	0.35
80 = 1 "	0.25

This difference of level between the two rails on curves is given by depressing the inner rail, and raising the outer rail one-half the quantity of difference required.

36. Professor Barlow in his "*Treatise on the Strength of Materials*," speaking of the Manchester and Liverpool railway, says, "I am disposed to estimate that about one in six of the plain butt joints is as perfect as can well be desired, and that another one in six is as bad as bad workmanship and negligence can make it; the remaining two-thirds varying in character between these two extremes;" this remark made, some ten or twelve years ago, may, we believe, with perfect justice, be applied to almost every railway constructed; by experiments then made, Professor Barlow found that the deflection of the rail on a bad joint was nearly 50 per cent. greater than on a good one; the writer of these pages has repeatedly noticed one rail to be one quarter and nearly one half inch higher than that at the end of it. What must be the concussion of a 20 ton locomotive going over such an obstruction at 30 or 40 miles an hour? Again, the joints are often nearly an inch wide, where they should not be one-eighth of this width, and the crushing of the rail at such a joint will be shown by the lamination after a

year's wear. These immense defects result solely from "bad workmanship and negligence;" and the engineer in charge of the construction of a railway should, by the utmost attention on his part, as well as on that of his inspector, discountenance such shameful practice. It will be found that plate layers, when once trained to a better kind of workmanship, will get on as well with it as with bad, and the wear and tear of stock, as well as the much less liability to accident, will amply repay this trouble. The utmost width of joint which should be allowed when the rails are laid in cold weather, is one-eighth, and in warm weather, one-sixteenth; this, of course, as closely as can be obtained in practice, for with our utmost care we cannot obtain perfection. Where the curves are sharp or numerous on a line of railway, a certain proportion of the lengths of rails should be made of an increased length to allow for the greater development of the curve at the outer rail.

37. By referring back to the articles in this chapter, the reader will observe, that the perfection of the permanent way, consists in the construction of the formation, and an efficient drainage of the same; the quality of the ballasting and the manner in which it is employed; the seating of the sleepers and chairs, and the fixing of the rails; the straightness of the line, or the regularity of the curve; the correctness of the levels; the fitting of the butting joints, and the transverse levels of the rails. It will be seen at once, and the more by greater consideration, that the soundness of the permanent way depends as a whole upon a number of minutiæ, and the expense of its maintenance, as well as its efficiency, will be exactly in proportion to the degree of attention given to each and all of these details being practically carried out.

CHAPTER IV.

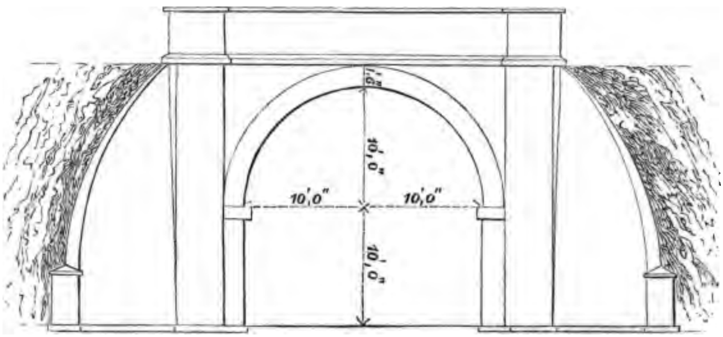
Setting out Works.

38. The constructive works on a railway consist principally of bridges and culverts, viaducts and tunnels, and retaining walls; and these are either on the square or on the skew, on straight lines or on curves. We will endeavour to point out the methods employed in practice for setting out these works, under these diffierent circumstances.

39. As the first case in bridges over or under roads, we will take the bridge, Figs. 28 and 29, intended to carry the railway over a road; the road is at right angles to centre line or nick A B, and the bridge will therefore be on the square; also the centre line of railway is straight; the span of the arch is 20 feet, and the half width of the bridge from the centre to the outside of the parapet is 15 feet, as C D; the face of the abutment will therefore be $15' \times 2 = 30'$. The centre line being stumped out, we have only to transfer the dimensions in the drawing on to the ground; set out the centre C, which will be in the middle of the road, unless any particular circumstance render it advisable to place this centre nearer towards A or B. But we will suppose it at C, and of course in the centre line of railway; from C set out 10 ft. towards A at E, and the same towards B at F, when we have the span set out; from E and F, set out E G and F H, both accurately at right angles to A B, the centre line, and upon E G and F H measure off 15 ft. for half the width of the faces of the abutments, as at I and K, and measure the distance I K, which should be 20 ft., if the first distances C E and C F have been accurately set out, and if E G and F H are both at right angles to A B, repeat the same operations on the other side of A B, and if the

lines be accurately set out, we shall have G I E and H K F, both produced; this being done, drive in stumps at G and H, and at G I E, and H K F, both *produced;* and note that

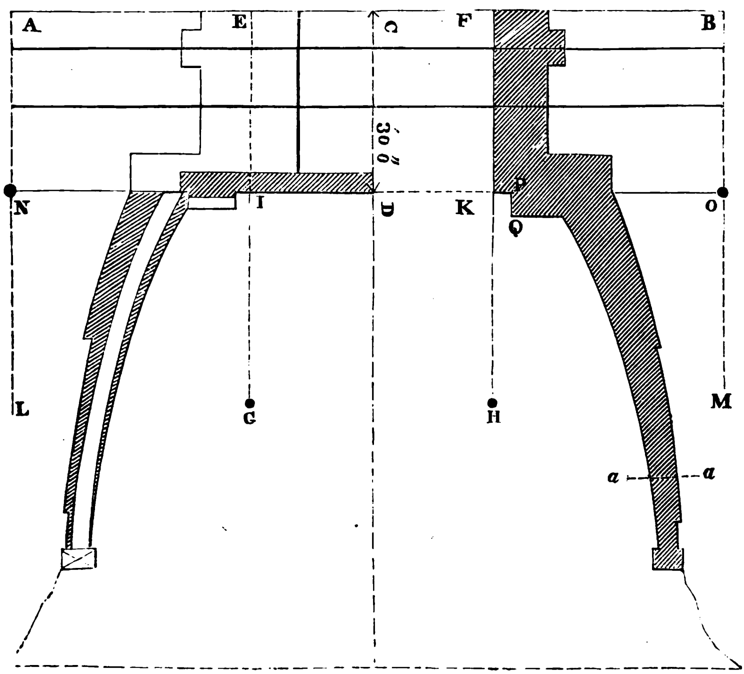
FIG. 28.



these stumps must be out of the way of the excavators, as by these stumps the masons have to line out the faces of the abutments. Now from the nick or centre line again, and at 30 or 40 ft. from the centre C, as at A and B, set out A L, and B M, also accurately at right angles to A B, and upon A L and on B M measure off 15 ft. again as at N and O, when N I K O will be one straight line, and drive in stumps at N and O, do the same thing again on the other side of A B, and we shall have the principal lines and dimensions set out, namely, the centre line A B, the faces of the abutments E I, F K, and the half width of the bridge by N O, also at any time when the centre line A B may be obtained; by these lines we may set out all the other dimensions. We have now to give the length of the wing walls, which length will depend on the height of the embankment; in this case it is 21′ 6, at slopes 2 to 1; this gives 43 ft. from the ends I and K of the abutment to the foot of the bank; but we have the newel, which is 4 ft. high, and which is constructed back into the embankment at the distance from the foot of 4 × 2 the ratio of slope = 8, and therefore the length 43 ft. — 8 will become 35 ft. for the length of the wing walls, which should also be stumped down; the distance K P, is equal to the depth of the arch stones; see the elevation, and the length P Q, depends on the batter or slope to be given to the pilasters; we will say 1 in. per foot, when, since the pilaster is 21′, 6″ in height, this be-

ing the depth of bank, we shall have 21½ in. of batter; to this must be added 3 in. for the projection of the short pilaster above the string-course, and we shall have 21½″ + 3″ for the

FIG. 29.



total projection of P Q. But this is on the supposition that the site of the bridge is perfectly level, which it is very likely not to be; Q may be 2 ft. lower, and 21½ will become 23½, or Q may to be 3 ft. higher, when we must deduct 3″, and make 21½ equal 18½, and every one of the four pilasters may be at different levels from the centre, and therefore would require a different projection for their batter. This last remark refers to wing walls exactly in the same way; for which reason we always "set out the slopes" at every road or site of bridge, and the difference of level being then correctly allowed for, we have but to multiply the height of the newel by the ratio of slope, say 4 × 2 = 8, and set out the end of the wing wall at 8 ft. inside of the foot of the embankment; when working drawings have been plotted without cross sections, these deviations from the

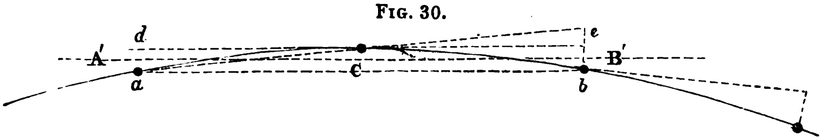
drawings are almost interminable. We will suppose, for instance, that in consequence of the ground rising, the end of the wing wall comes at *a a*, instead of where it is shown at Fig. 29; we should have to transfer the thickness of the wing as shown on the drawing at the newel to this new situation for it, which would alter the dimensions all along; a short practical rule for determining the mean thickness of wing walls, is to multiply the height by .25, which will give a quarter of the height for the *mean* thickness: for heavy masonry, .22 will be sufficient. In setting out the wing walls, an allowance must be made for batter according to height, if an inclination is to be given to them. In the simple case which we have had under consideration, it is scarcely possible to commit any error; but we have been minute, because if the dimensions were all treble, we should proceed by the same means.

40. In setting out, measuring rods are far preferable to tapes, and we also use about half a dozen short boning rods, about 5 ft. long, and a good line, which may be procured from the masons; and in setting out a right angle, where the lines are long, we also make use of a box sextant, which is *most accurate, quickly used, and may, without being felt, be carried in the pocket;* in short, we strongly advise the assistant-engineer to neglect no means to make his work accurate, and to employ every mechanical means which may aid him in doing this; the rapidity also with which the various operations of setting out are performed, will depend upon his knowledge of the application of mechanical means.

41. As a second case, we will set out a bridge carrying the railway over a turnpike road, and a stream running by the side of it; the centre line of railway is on a curve of 60 chains radius, and the road is at right angles to the centre line. Let Fig. 30 be the curve; if we were to set out the faces of the abutments at right angles to this curve, we should have a conoidal instead of a cylindrical ring for the arch, and the span at one end would be considerably greater than at the other. If we were to set out the work in this manner, it would be by setting out perpendiculars at right angles to the chords, and these perpendiculars would not be parallel, because the contiguous chords are not parallel; to overcome this obstruction, it is usual in prac-

tice to proceed in the following way:—Fig. 30 being a curve of 30 chains radius, the offset, when setting out by chords, would

Fig. 30.



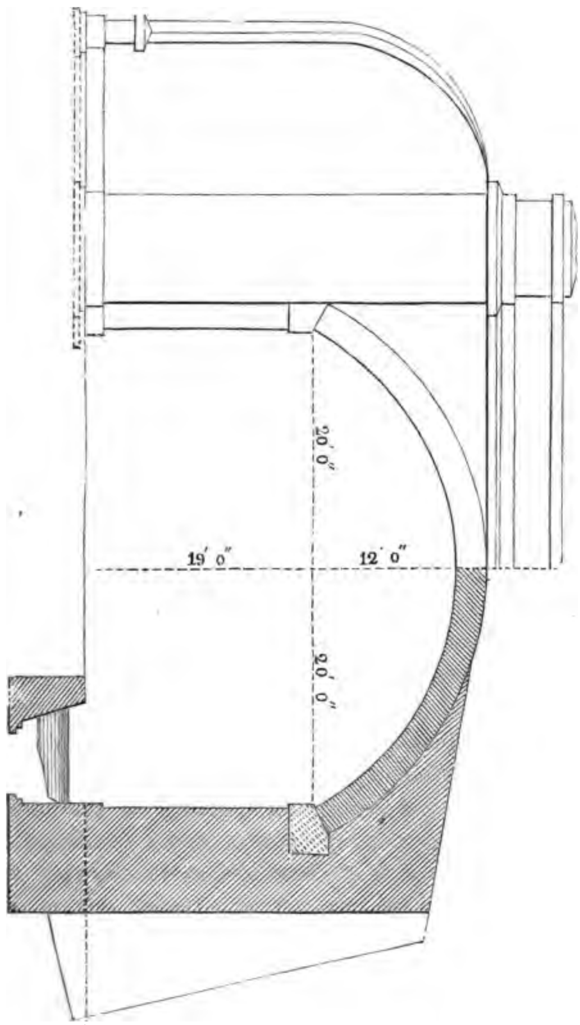
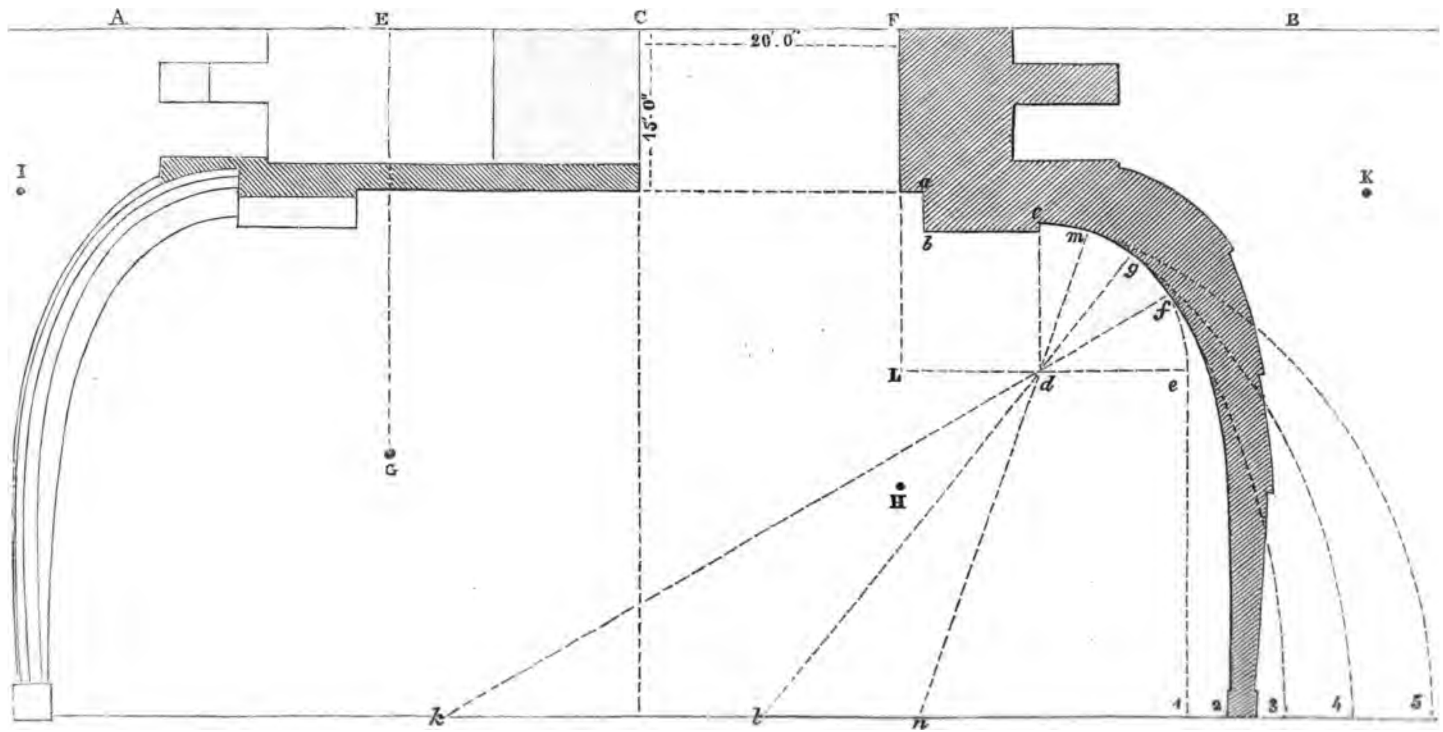


Fig. 32.

be 13.2 in inches, and if setting out by tangents, it would be $\frac{13.2}{2} = 6{\cdot}6$; set out one quarter of 13.2, or one half of 6.6, which is equal to 3.3 in inches; from stump *a* and stump *b*, towards the outside of the curve, set out 3.3 as at A and B, and from stump *c*, set out the same dimension 3.3, toward the inside of the curve at C; we shall thus obtain a line, A C B, which will be at a mean distance between the chord *a b*, and the tangent *d e*, and on which we can set out the dimensions of our bridge on the square. Now let A C B, Fig. 31, represent A′ C′ B′, Fig. 30; we proceed, as shown at Art. 38, by first setting out the span of 40 ft., 30 ft. for the width of the turnpike road, and 10 ft. for the width of the stream, on account of which latter the centre of the arch will not be over the centre of the road: E C F being the span of 40 ft. on the straight line A B, set out E G, F H at right angles to A B; produce the line thus sighted to the other side of A B, set out the half faces of the abutments, measure from face to face at each end, that the spans at each side of the bridge be equal; set out I K, at 15 ft. from the centre line A B, and on each side of it, and see that these points are perfectly in line with each of the faces of the bridge; we have now found our principal lines, and have but to set out the batter of the pier with due attention to the projection for batter being proportioned to inclination per foot and height of each pilaster relative to the centres of abutments E and F.

42. Wing walls are built to prevent the earth in the slopes of the embankment from spreading over the road, and it is necessary that they do this effectually, without danger of being overturned or deformed with lines mutilated by bulging out. It was customary some years since to give them a considerable spread, thereby increasing the quantity of masonry, besides making a bridge of a single arch, quite a secondary feature in comparison to its outspreading and overshadowing wings. It is too common a practice, merely to mark out on the ground the extreme length of the wing wall, and to leave the foremen of masons to settle the rest as best they may. From long practice on railway works, many of these men possess a knowledge

FIG. 31.



deduced from experience, which they apply with an intelligence and earnestness deserving of great esteem; but there are also a greater number of them who are totally ignorant of all practical means for doing the work, unjustly left to them by idleness or ignorance equal to their own; and but too often the result is a wing wall of crooked curvature, with a tumbling appearance which would do credit to the efforts of a thousand years, to say nothing of the real weakness of such brickwork or masonry, if it deserve not rather the name of a heap of rubbish. The following methods will be found as practical as they are simple: set out the projection of the pilaster *a b*, and the return, and make *c d* equal to the width of the pilaster, and parallel to F H, by measuring off from the face of the arch in the direction of H, a distance equal to the projection, plus the width of the face of pilaster, as at L, and from L a perpendicular equal to the depth of arch stone, plus also the width of the face of the pilaster. For number 1, pin a mason's line at centre *d*, and with the length *d c* describe the quadrant *c e*, from which produce the tangent *e* 1; this method is, however, only applicable where the length of the wing wall does no exceed 15 or 20 ft., because the straight line *e* 1 is by no means so well adapted to resist thrust as a curved wall. For number 2, describe the curve *c f* from the same centre, but make *c f* equal to *c d*, produce *f d* to *h*, making *f h* equal to 3 times *f d*, and from *h* with a tight line describe the curve *f i* from any point of which you may produce a tangent to the site of the newel as *c f i* 2; for the reason above assigned, the straight line should never be longer than one-third or one-half of the total length, unless there be compulsive existing circumstances from locality. For number *c* 3, describe the curve again from centre *d*, and again make *c f* equal to *c d*, produce *f d* to *k*, which is at an equal distance from the face of the bridge at 3, and from *k* describe the arc *f* 3. For number *c* 4, still making *d* the first centre, and with same radius *d c*, describe the arc *c g*, making *c g* equal to two-thirds of *d c*, producing *g d* to *l* at the same distance from the face of the arch as 4, and from centre *l* describe the arc *g* 4. For number *c* 5, *c m* is but one-third of *c d*, the centre of second arc being produced being at *n* on *m d* produced; the two latter curves, from their wide sweep, are adapted to the wing walls of

a viaduct rather than to a bridge. By adopting any of these methods, it is not to be supposed that the lines drawn on paper are to be transferred to the ground; it will be sufficient to give a few points on the curves, and to leave the centres well fixed for the reference of the masons, who will perfectly well know how to employ them. By assuming as a first radius a length equal to the width of the pilaster, the curvature is always adapted to the magnitude of the work, in the same manner as the pilaster.

43. An oblique direction of a river, road, canal, &c., may render it necessary to spread the wing wall to a considerable distance back into an embankment, when it will be much easier and fitter to set out the curve by ordinates found on the chord at equal distances from the middle of it, and for doing this there is a simple practical rule, when we have the length of radius and that of the chord. In Fig. 33, let B, the radius, be 80 ft., and C, the chord, 50 ft., for curve A B.

$$\sqrt{R} - \left(\frac{C}{2}\right)^2 = \text{Cos.}$$

$$R - \text{Cos.} = \text{Vers. Sin.}$$

$$R^2 = 80^2 = 6400.$$

$$\left(\frac{C}{2}\right)^2 = 25^2 = 625.$$

$$\text{and } \sqrt{5775} = 76 = \text{Cos.}$$

$$(R)\ 80 - (\text{Cos.})\ 76 = \text{V. S., } 4.$$

V. S. equal to 4, will therefore give us one point on the curve as at S. We now want to obtain the length of the ordinates at given distances from the middle of the chord A B, that is, at given distances from the versed sine V. S.; say first 10 ft.

$$\text{From } R^2 = 6400$$

$$\text{Deduct } Va^2 = 100$$

$$\text{From } \sqrt{\text{Diff. } 6300} = 79.36 \text{ deduct the Cos. } 76.$$

$$\underline{76.}$$

$$3.36 = a\,a.$$

3.36 is then equal to the ordinate $a\ a$, $a'\ a'$ at 10 ft. from V S, and by the same rule we may find any number of points in the curve, each calculation supplying 2 points at equal distances from the middle of the chord A B. When the foundations

have been excavated and the masonry brought up to the level of the surface, a few points may be thus set off for the curve,

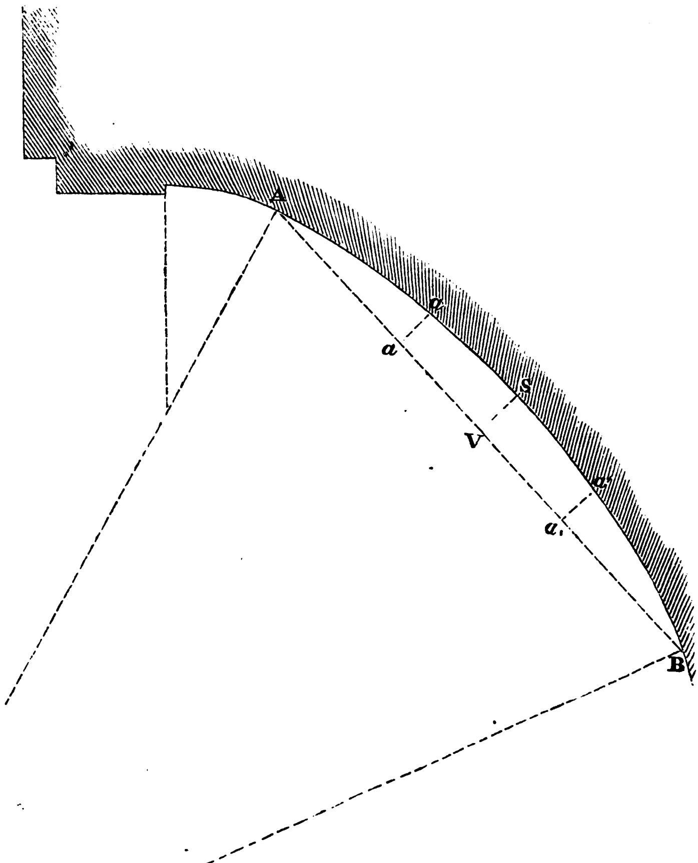


FIG. 33.

and this precaution will remove all danger of an unsightly wing wall. It is very much to be hoped that the reader will now be persuaded of two things: how easy it is to avoid a series of unequal curves joined by short straight lines at all possible angles, and to obtain a wall of regular curvature throughout; and that in a viaduct, a bridge over a river or turnpike road, however simple the design and rough the materials, if the work be correctly set out with regard to curvature and inclination, it will always surpass in elegance the most finished design and highly wrought materials, carried out and

put together without attention to the particular points on which we have dwelt at a length which may appear fastidious, but nevertheless considered necessary from the very slovenly manner in which this work is too often done.

44. In setting out a bridge in a cutting, we proceed by similar means, finding the centre line of railway A B, and the centre line of the road, the intersection of which lines will of course be the centre of the bridge; from the centre line C D, Fig. 34, set out the faces of the abutments, each of which will be at a distance from the centre equal to the span, and make these lines of faces secure by stumps; the length of the wing walls will be regulated by the width of base of slopes, and will, in sidelong ground, be longer on one side than on the other, and before they can be accurately fixed, the edge of the slopes will require to be determined carefully; the two short pilasters terminating the wings should stand clear of the slopes. Bridges carrying roads over railways in sidelong ground, will require strict attention to the original or new inclination of the road. Fig. 35 shows a bridge under a level road; but suppose the gradient to be 1 in 30, and the distance from centre to centre of pilaster to be 36 ft., the top of the pilaster A will be 1.20 higher than pilaster B; any neglect on this score would produce at least a crooked string course, and the metalling of the road over the bridge being higher up along the parapet at one end than at the other, besides the necessity of raising the parapet to obtain the four feet height above surface according to "standing orders." In Fig. 35, let the dotted line C D represent the gradient, C, D, being the edges of slopes; by levelling from C to D we obtain the difference of levels.

$$\text{C D} = 92.00$$
$$\text{Diff. of levels} = 3.06.$$

From D to O = 44 ft., and from O to B = 18; 44 — 18 = 26; and difference of levels for 26 ft. = .86, and for 44 ft. = 1.46; and 1.46 — .86 = .60 difference of level between crown of arch and pilaster B; but the crown of the arch is 20 ft. above railway formation, and 20 — .60 = 19.40 for height of B pilaster, and for A 20 + .60 = 20.60, and for the batter of pilaster at 1 in. per foot we shall have for B 19½ in., and for A 20½. In practice, having the gradient, we have but to deduct it from or

add it to the height from formation to the crown of the arch, to

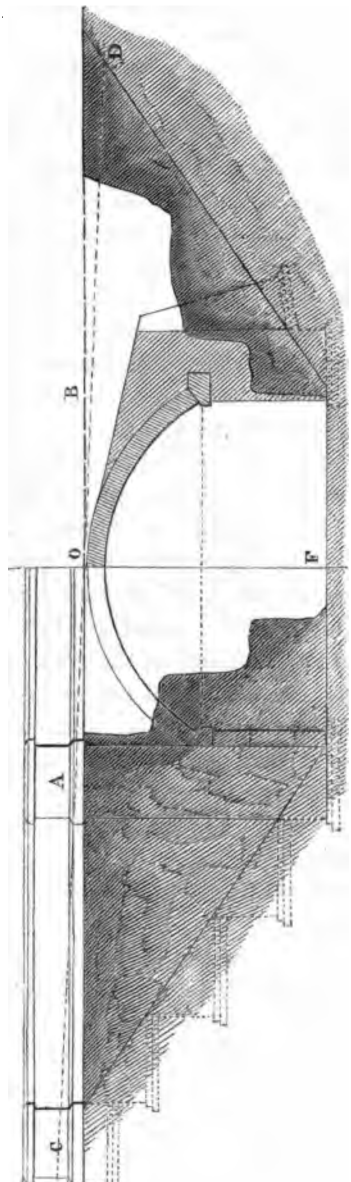


FIG. 35.

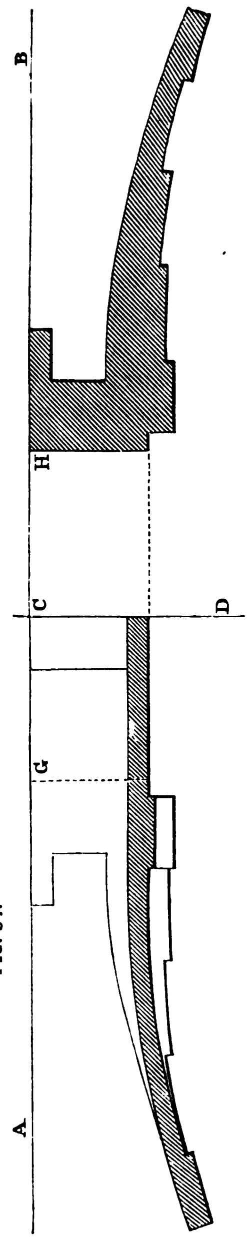


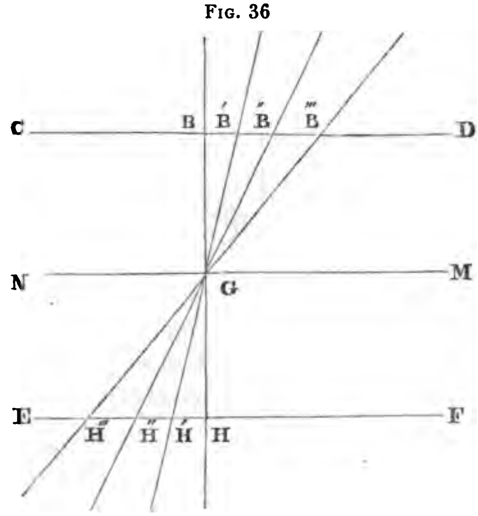
FIG. 34.

ascertain the height of each pilaster. When about to set out a

bridge in a cutting, the engineer will often find that he has to do this in very rough ground, as at Fig. 35; and as we should have to bone out over the very uneven surface C A F D, the eye would be very likely to get out of the lines A B, Fig. 34, and C D, Fig. 35; but if we fix C D correctly, and strain a line from A to D, we can find G H with due precision. This precaution will be found the more requisite in deep cuttings, where three arches often span the excavation, the centres of which, as well as the centres of the piers and abutments, must all be in one line, and an error, whatever it may be, will be a miserable distortion which must be ripped up at one side and patched upon the other. By using a plumb line at about A or D, Fig. 35, we can easily make it coincide with that strained across the cutting, and thereby sight out the centres of abutments or piers.

45. The methods of setting out on the square being well understood, there will be no difficulty in readily apprehending the means employed to set out works on the skew, in which either the faces of abutments are at a given angle, and the faces of the arch parallel to the centre line of railway, as when the bridge

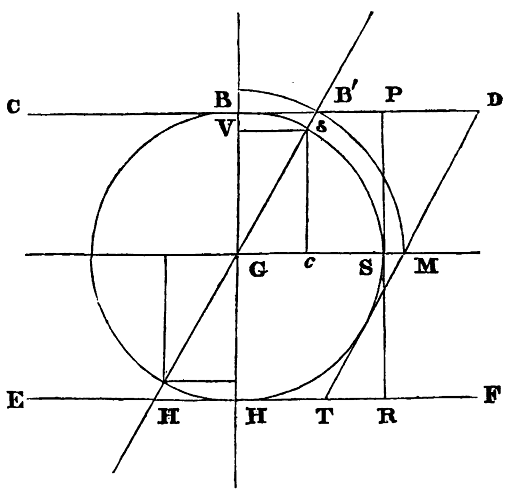
FIG. 36



carries the rails over a road or river, or the faces of the arch are at a given angle, and the abutments are parallel to the centre nick as when the bridge carries the road over the railway; in

either case, the dimensions on the square being given, these will always remain the same *on the square,* however the skew dimensions may vary, which will be with the angle of skew, as in Fig. 36, in which let G B, G B′, G B″, G B‴, be the centre line of railway, when C D, E F, will be the lines of the faces of the arch; but if G H, G H′, G H″, G H‴, be the centre line of road, then will C D, E F, be the lines of the faces of the abutments; and G B, or G H, being the lengths on the square, G B′, G B″, G B‴, or G H′, G H″, G H‴, will be the lengths on the skew, and these latter lengths will become greater, as the sine of the angle G becomes less; the skew length, therefore, is in the inverse ratio of the sine of the angle of skew G M B‴, &c., G N H‴, &c.; we have therefore ready means of ascertaining the skew lengths. In Fig. 37, let B H be the span on the

Fig. 37.



square, and let B′ H′ be the span on the skew, B′ G M being the skew angle, the value of which has of course been ascertained by instrumental measurement, C D, E F, being the lines of the faces of the abutments. In the right angled triangle B G B′,—

$$v\,G : G\,s :: B\,G : G\,B';$$

but $v\,G = s\,c,$

and $s\,v = c\,G;$

and B G and G s are each = radius,

G B′ = cosceant,

and *s c* is the sine, and *c* G is the cosine of the angle B′ G M of skew; hence we have:—

$$\text{sine of angle} : \text{radius} :: \text{radius} : \text{cosceant};$$

or,

$$\frac{\text{radius}^2}{\text{nat. sine}} = \text{cosceant};$$

or,

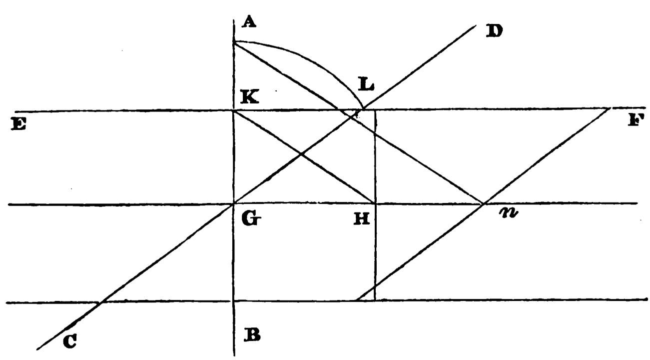
$$\frac{\text{span on the square}^2}{\text{natural sine}} = \text{half span on the skew.}$$

Having found the span on the skew, we have next to ascertain the width of abutments on the skew. Make B P, Fig. 37, the half width of abutment on the square, equal to the half span on the square, as, for instance, we should have in crossing a 30 ft. road, with 30 ft. for the width of formation; through P draw P R, parallel to B H, and with radius G B′ describe the arc B B′ M; through M draw D M T parallel to B′ H′. In parallelograms B G *s* P, D M G B′,

$$\text{B P} : \text{B G} :: \text{B}'\text{D} : \text{B}'\text{G};$$
$$\text{and B P} = \text{B G, then B}'\text{D} = \text{B}'\text{G};$$

and the half skew width of abutment D B′ is equal to the half skew span G B′, when, on the square, these dimensions are equal. In Fig. 38, let A B be the line on the square of the road, C D

Fig. 38.



the line on the skew, and E F a line of one face of abutment; G H is the half width on the square, and K G the half span on the square; the length of G L, the half skew span, we can obtain as above, Fig. 37, having the angle L G H. Make L M

perpendicular to C D, and equal G H the half width on the square, and draw F B parallel to C D; join K H, make G A equal to G L, the half skew span, and make A *n* parallel to K H. In the right angled triangle A G *n*,—

$$KG : GH :: AG : Gn,$$

but,

$$AG = GL,$$

therefore.

$$KG : GH :: LG : Gn;$$

and in parallelogram G F,

$$Gn = LF;$$

then,

$$KG : GH \text{ or } KL :: LG : Gn \text{ or } LF;$$

but,

$$KG = \text{half square span},$$
$$KL = \text{half square width},$$

and,

$$GL = \text{half skew span},$$
$$LF = \text{half skew width};$$

therefore,

half square span : half square width : : half skew span : half skew width.

The following tables of half skew spans have been constructed to expedite these calculations; where the skew span is 30 ft., having the angle of skew, we have but to refer to the angle in the tables, and alongside of it will be found half the skew span; if the span on the square is more or less than 30 ft., it will be but a simple matter of proportion to find the corresponding skew span; as for a 40 ft. square span at an angle of 50°,00; the tabular number for 50°,00 is 19.58, then

$$15 : 19.58 :: \frac{40}{2} : 26.10;$$

and 26.10 × 2 = 52.20 for the skew span. And for the skew width, with 20 ft. on the square width we have,

$$\frac{40}{2} : \frac{20}{2} :: 26.10 : 13.50.$$

TABLE

Of Skew Lengths for 15 *feet on the square; or radius* = 15, *Cosceant* = *Tabular Number.*

Angle of Skew.	Skew Length.	Angle of Skew.	Skew Length.	Angle of Skew.	Skew Length.
25°,00	35.49	31°,00	29.12	37°,00	24.92
10	35.27	10	28.98	10	24.83
20	35.05	20	28.84	20	24.73
30	34.84	30	28.70	30	24.64
40	34.63	40	28.57	40	24.55
50	34.42	50	28.44	50	24.46
26°,00	34.19	32°,00	28.30	38°,00	24.36
10	34.01	10	28.17	10	24.27
20	33.61	20	28.05	20	24.18
30	33.62	30	27.92	30	24.10
40	33.42	40	27.79	40	24.01
50	33.23	50	27.67	50	23.92
27°,00	33.04	33°,00	27.54	39°,00	23.83
10	32.85	10	27.42	10	23.75
20	32.67	20	27.30	20	23.67
30	32.48	30	27.18	30	23.59
40	32.30	40	27.06	40	23.50
50	32.13	50	26.94	50	23.42
28°,00	31.95	34°,00	26.82	40°,00	23.33
10	31.78	10	26.71	10	23.25
20	31.61	20	26.60	20	23.18
30	31.43	30	26.48	30	23.10
40	31.27	40	26.37	40	23.02
50	31.10	50	26.26	50	22.94
29°,00	30.94	35°,00	26.15	41°,00	22.86
10	30.78	10	26.04	20	22 71
20	36.62	20	25.94	40	22.56
30	30.46	30	25.84	42°,00	22.41
40	30.31	40	25.73	20	22.27
50	30.15	50	25.62	40	22.13
30°,00	30.00	36°,00	25.52	43°,00	21.99
10	29.85	10	25.42	20	21.86
20	29.70	20	25.32	40	21.72
30	29.55	30	25.22		
0	29.41	40	25.12		
50	29.26	50	25.02		

TABLE

Of Skew Lengths for 15 *feet on the Square; or Radius* = 15, *Cosceant* = *Tabular Number.*

Angle of Skew.	Skew Length.	Angle of Skew.	Skew Length.	Angle of Skew.	Skew Length.
44°,00	21.59	55°,00	18.31	71°,00	15.85
20	21.46	20	18.20	30	15.82
40	21.34	56°,00	18.09	72°,00	15.76
45°,00	21.21	30	17.99	30	15.73
20	21.15	57°,00	17.89	73°,00	15.68
40	20.97	30	17.78	30	15.65
46°,00	20.85	58°,00	17.69	74°,00	15.60
20	20.73	30	17.59	30	15.57
40	20.62	59°,00	17.50	75°,00	15.53
47°,00	20.51	30	17.41	30	15.50
20	20.40	60°'00	17.32	76°,00	15.46
40	20.29	30	17.23	30	15.43
48°,00	20.18	61°,00	17.15	77°,00	15.39
20	20.08	30	17.07	30	15.36
40	19.98	62°,00	16.98	78°,00	15.33
49°,00	19.87	30	16.91	30	15.30
20	19.77	63°,00	16.83	79°,00	15.28
40	19.68	30	16.76	30	15.25
50°,00	19.58	64°,00	16.69	80°,00	15.23
20	19.49	30	16.62	81°,00	15.19
40	19.39	65°,00	16.55	82°,00	15.15
51°,00	19.30	30	16.49	83°,00	15.11
20	19.21	66°,00	16.42	84°,00	15.08
40	19.12	30	16.36	85°,00	15.06
52°,00	19.03	67°,00	16.29	86°,00	15.04
20	18.95	30	16.24	87°,00	15.03
40	18.86	68°,00	16.18	88°,00	15.02
53°,00	18.78	30	16.12	89°,00	15.01
20	18.70	69°,00	16.07		
40	18.62	30	16.01		
54°,00	18.54	70°,00	15.94		
20	18.46	30	15.91		
40	18.39				

46. We can now proceed to the practice of setting out works on the skew, and as an example we will take the bridge shown at figures 39 and 40, the skew angle of which is 55°,30, and the span on the square 36 ft. By the tables we obtain 18.20 for 15.00 on the square, at an angle of 55°,30′. We have then the following proportion :—

15 : 18 : : 18.20 : 21.84;

therefore 21.84 will be our half skew length, by *S*. And for the half *skew* width we have the next proportion, without referring to the tables, although we have 15.00 for the half *square* width,

18 : 21.84 : : 15 : 18.20;

therefore 18.20 is the half skew width. And we have now our skew dimensions, 43.68 and 36.40. Now proceed to setting out on the skew centre lines A O A′, D O E, as shown at *S*, for setting out on the square. That is, from any point A, on one centre line, at *right angles* to A O, set out the *square* dimensions of 15′, on each side, as at B, and C, and do the same thing from A′, at B′ and C′. On the centre line D E, at any points D and E, set out also at *right angles* the *square* dimensions of 18′, on each side of D E, as at F and G, and at F′ and G′; the intersection of these lines will give the points K, L, M, N, and K L, M N, will be the skew faces of the bridge, and K N, L M, will be the skew faces of the abutments. Now measure K L, and N M, and if each respectively give 43.68, or 43′, 8″, then D E, the centre of the road, will be at an angle of 55°,30″ with the centre line A A′, but not otherwise. The angle, or supposed angle of skew is generally measured from the plan, and the drawings made in the office, and the skew proportions given accordingly; unless the plan be very correct, there may be, and often is, a considerable difference between the angle of skew on the drawing and the angle on the ground, that is, the angle formed by the centre line of the railway, and the centre line of the road; this absurd discrepancy can always be obviated by measuring the skew angle on the ground before the drawing is commenced as we have pointed out in the commencement of these pages. When, however, this discrepancy is found to occur, many persons shift the centre of the road E D, more or less one way or the other, until the right dimensions for K L,

N M, are obtained, and a very slight deviation of D E will materially alter the angle; this is called "fitting" the work, and the reader may form judgment for himself as to what it ought to be termed. By setting a box sextant to the given angle, and standing on the centre line A A′, and as near as possible to O on the centre line D E of the road, set out the angle, proceed as above with setting out the dimensions, and the matter is settled without any "fitting." Make fast the points C, B, C′, B′, F, G, F′, G′, and the faces of the bridge as well as the faces of the abutments may at any time be found, as well as their skew dimensions. In setting out skew bridges, attention should be given that the projection for the batter of the pilaster project not into the line of the face of the abutment. With regard to the wing walls, it may be mentioned that on level ground the four newels would include a rhomboid, of which the sides would be parallel to the sides K L M N, from which they would deviate as the ground, according to the rise or fall of the ground on one side or the other. In K R, M R′, the radius of the first circle is equal to the width of the pilaster, and the centre is on a line at right angles to the face of the bridge, and the chord of the circle is equal to the radius; the radius of the second arc is found by sighting the line from the end of the first arc through the centre on to the foot of the slope, or thereabouts. S, S′, are at a distance from the centre of the road equal to that of R, R′, from the same centre line, and the radius of L S, M S′ may be made equal to the chord. It will be perceived that by lengthening the first arc of K R, M R′, the terminal or newel may be brought nearer to the centre line D E; however, these wings may be set out, every care must be taken that the newel be the most distant part of the wing wall from the centre line D E, or a very deforming effect will be produced. Skew bridges are expensive structures not only from the increased dimensions of the body of the bridge, but also from the extension of the wing walls; where in heavy embankments it is more economical to bring the wings into the body of the embankment, straight with the faces of the bridge, and terminate them at a distance equal to the depth of the embankment multiplied by 1½ or 2, and thus slope the embankment down to the pilaster, or a short dwarf wall may be constructed in line with the length of the abut-

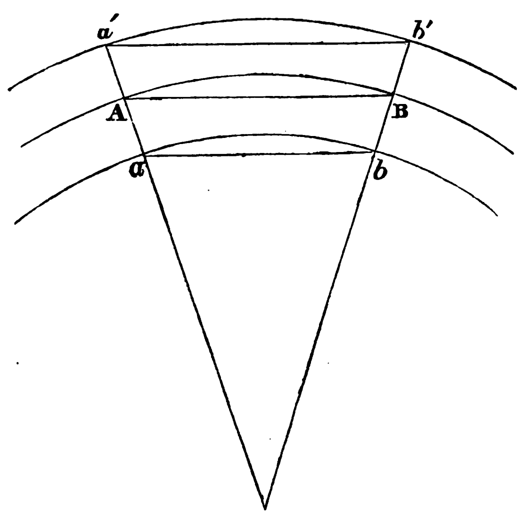
ment. The case above given being in embankment, where the ground would be clear and free from encumbrances, would not offer the same obstacles as a skew bridge in a deep cutting, when the beginner would find it necessary and advisable to have recourse to the means pointed out at Figs. 39 and 40, in order to secure accuracy with regard to the centres, the dimensions, and the angles of the piers and abutments; but in this, as in all the former cases, the rules given, and methods pointed out in the foregoing pages, are in every sense so strictly practical, that the student, after due attention and thought bestowed on them, may be perfectly confident of success if he be careful, and if he be not misled by the "rough and ready school," and induced to have recourse to "fitting.

47. The methods of setting out viaducts on the square or on the skew are so analogous to the preceeding cases, that it would be but a repetition to go into them, with the exception, however, of its being advisable to set out the lines of the centres of the arches as well as those of the faces of the piers and abutments, the stumps noting the lines for the arches being less liable to disturbance than those of the piers and abutments even when kept at a distance from such heavy works as a viaduct, and it need not be added that equidistance and perfect parallelisms are essentials in setting out such a work. With regard to the levels, instructions will be found in the next article, which will treat of setting out a viaduct on a curve.

48. In setting out a viaduct on a curve, the first points to be obtained on the ground and on the centre line, will be the centres of the arches; and the distances of these from each other will depend on the dimensions of the span and the thicknesses of the piers, and each of them must be set out on a curve of a given radius, which should be done by chords or by tangents. The subject of setting out curves having been treated on in the first part of the "Assistant Engineer's Guide," but little will be said on the subject here. By dividing the distance in inches by the number of chains in the radius, we shall get the offset to the chord as nearly as it can be set out, and half this offset only will be used when setting out by tangents. In Figs. 41 and 42, we have a viaduct on a curve of 40 chains radius, the distance from centre to centre being 30 ft. for the span, and

4′, 6″ for the thickness of each pier; 30′ + 4′,6″ = 34′,6″ will therefore be the distance from centre to centre, either of the arches, or of the piers, or 414″, and 414 ÷ 40 = 10″.3, in setting out by chords, or 5.1 in setting out by tangents; let A, B, C, D, E, be these centres of arches on the curve A E. In Fig. 41 it will be seen that the arches are all square, that is, that the span of the face nearest to the centre of the curve is equal to the span of the outer face, each being of 30 ft.; were it otherwise, we should have a conoidal arch, and this of course will greatly increase the inequality of the piers at each end. Now in these cases, the difference between the arc and the chord is so small, that it may be disregarded, and we may assume the length of the chord for that of the arc, in calculating the difference

Fig. 42.



between the lengths of A B, *a b*, *a′ b′*; let A O, B O be radii of 40 chains, or 2640 ft., *a* O, *b* O, radii 2640 — 15 = 2625 ft., and *a′* O, *b* O radii of 2640 + 15 = 2655 ft., that is, assuming the transverse axis of our arch as 30 ft.; we have

A O or B O : A B :: *a* O or *b* O : *a b*, that is,

2640 : 30 :: 2625 : 29.82, or 29′ 10″ nearly,

and 30′ — 29′,10″ = 2″;

that is, that 2″ is the quantity which we shall have to deduct from the thickness of the piers on the inner side of the curve in

order to make $a\,b = \mathrm{A\,B}$, that is 30 ft., half the difference, or 1′ being deducted from each side. By the same reasoning we have

$$\mathrm{A\,O} : \mathrm{A\,B} :: a'\,\mathrm{O} : a'\,b', \text{ that is,}$$

$$2640 : 30 :: 2655 : 30.17, \text{ or } 30',2'';$$

we have therefore 2″ again for the difference, half of which is to be added to each side on the pier at the end on the outer curve.

Moreover we have

$$2640 : 4.50 :: 26.25 : 4.47;$$

and as

$$2640 : 4.50 :: 26.55 : 4.53 \text{ nearly,}$$

therefore at the end nearest the centre, the thickness of the pier will be

$$4.47 - .18 = 4.29,$$

on the centre line 4.50 as given, and at the end of the pier, on the outer curve, or the farthest from the centre of the circle, we shall have

$$4.53 + .17 = 4.70.$$

The above calculations have only been gone into to show what the dimensions of the piers will be, as also to explain more fully the principles on which such a work as a viaduct on a curve is set out. With regard to the practice, having found the centres A, B, C, D, E, Fig. 41, set out lines perfectly at right angles to the common chord, shown at A, as at $a\,\mathrm{A}\,b$, $a'\,\mathrm{B}\,b'$, $a''\,\mathrm{C}\,b''$, $a'''\,\mathrm{D}\,b'''$, &c., producing them sufficiently out of the works that the stumps, securely driven in, may be easily found again; and let it be remembered, that if these centre lines of arches are lost by the stumps being pulled up, the work will require fresh setting out, when the ground may not be in a very convenient state for doing so. Having now found the centre lines of the arches, measure off from A towards *a*, and towards *b*, half the width of the viaduct, say 15 ft., as at F and G; also from A set out on the centre line, half the span as at 1 and 2, and from 1 and 2 on each side of the centre line, and at right angles to the *common* chord, set out again half the width of the viaduct, 15 ft., as at H, K, L, M, when H F and F L will each measure half the span, as will also K G and M G, if the dimensions have been correctly set out. Now from cen-

tre B proceed in the same manner, as first on a' B b', on which set out N and O; then from B on the centre line, say off 15 ft., at B 3 and B 4, next 3 P and 3 Q, also 4 R and 4 S; check as before, when P N, R N, Q O, S O, will each measure half the span. And now measure the two ends of the piers, when L P should measure 4.70, and M Q 4.47; treat the arches C, D, E, &c. in the same manner, when the position and dimensions of all the piers and abutments will be set out, and consequently the uniform span of the arches; in setting out in deep water, staging, and if necessary, boats or rafts are provided. With regard to batter, this is generally a matter of levels, when the batter reaches to the foot of the piers; in Fig. 42, the sides of the piers are plumb for a certain depth from the surface; but suppose the batter to be $\frac{1}{4}$ in. per foot, at depth 47.25 we shall have for batter 47.25 — 10′.00 for rise of arch, and springer $= 37.25 \div 4 = 9\frac{3}{4}''$, near enough for practice for batter on each side; and at 59.15, we shall have a similar calculation, due attention being given in every case to take the gradient into calculation, and to operate only on the depth *below the springer.* Having carefully taken the levels over *the site of the piers*, checking on all B M s, the heights to formation are easily obtained, from which deducting surface height from datum, and from the remainder the rise of the arch and depth of springer, carefully including the depth of the level of springer, as at Fig. 43, we obtain the height of the pier. Care is required in doing this, as it is the only means of obtaining a true and uniform batter, and avoiding a distorted line which always shows itself strongly in the arrises of the piers.

49. In the curves which we usually set out in railway works, the versed sine bears but a small proportion to the length of chord; but for reservoirs and other engineering works, we may have to set out curves where the versed sine may bear a much great proportion to the chord, as in Fig. 44, where let A B be the chord, and V S the versed sine; set out A C from A, and B D from B, each equal to V S, and at right angles to the chord A B; also from A, set out A E, at right angles to A S; and from B, B F, at right angles to B S; through C, S, D, set out E F at right angles to S V; divide A B into any number of equal parts, as at 1, 2, 3, 4, &c., and picket them; divide E F

into an *equal number* of equal parts, as at 1′, 2′, 3′, 4′, &c., and plant rods at each; and now divide A C, and B D, each into an equal number of equal parts, as at G, H, I, K, &c., G′, H′, I, K′, &c., and stump these also. Now standing at 1, bone out 11′, and an assistant standing at G, let him bone out G S; intersection *a* will be a point on the curve; repeat the same at 2, and at H, when *b* will be a second point on the curve; again at 3, and at I, and *c* will be a third point, until we have also *d*, *e*, *f*, *g*, *h*, *k*, *l*, *m*, *n*, *o*, *p*. Of course A B may be divided into any number of feet, from V to B, and V A. This method only applies where A B and V S are accessible lines, but where this is the case, and where a considerable number of points on the curve are required, and A B only 200 or 300 yards, it is an expeditious and accurate way of getting the curve.

50. In setting out culverts in sidelong ground, attention must be given to the length required for the arch; in general it will be sufficient to set out the foot of the slope with accuracy, and multiplying the total height of the culvert by the ratio of slope, set back the result for the end of the arch, as in Fig. 45, where the base of slope is 53.50; height of culvert, 8.50, and this by 1½ is equal to 12.75, when we have to set back 12′,9″ from the foot of the slope. Cases, however, occur, where this is not sufficient. In Fig. 45, the height of embankment on the nick is 23 feet, and the height of culvert 8′,6″; this from 23 ft. leaves 14.6, for which height the base of the embankment would be 36′,9″, and to this add the fall per foot, multiplied by the ratio of the slope; of course this last quantity would have to be deducted on the higher side of the ground.

51. In setting out the bevels of springers to segmental arches, the following proportions are to be observed; in Fig. 46.

$$OR : OS :: RT : RV;$$

that is,

as the radius is to half the span, so is the depth of arch stone to R V; and

$$OS : RS :: RV : TV:$$

that is,

as half the span, is to the radius minus the rise of the arch, so is R V to T V the rise of bevel.

For the extrados thickness of arch stones,

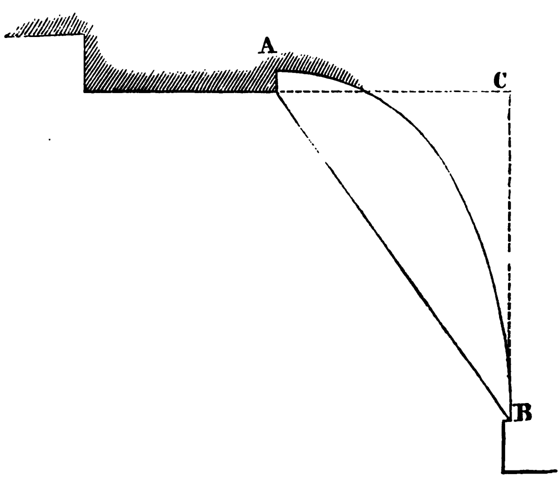
$$OR : Ra :: OT : Tb;$$

that is,

as the radius for the intrados, is to the thickness of arch stones at the intrados, so is the same radius plus R T, or the depth of the arch stone, to T B.

52. To set out the slope of a wing wall under the coping, on the masonry, has been as yet omitted; to do which we may use the following simple means:—in Fig. 33 *a*, let A be the point in the pilaster and abutment where the top of the wing wall runs in, and let B be the top of the newet; strain a line between

FIG. 33 *a*.



A and B, and fasten it down at those points; set out C square with A and B on the top of the embankment, and make C *level* with A the top of the pilaster; by stretching a line from C to any point on the line A B, we get the required level of the wing wall under the coping, wherever the second line touches the top of the masonry, each of the lines being in the inclined plane A B C.

CHAPTER V.

EXPERIMENTS BY GEORGE RENNIE, Esq.

No. 1.

On the Transverse Strength of Wooden Beams resting on rollers, 3 ft. 9 in. apart.

Species of Timber.	Sectional Dimensions.	Breaking Weight.
English Oak	2″ × 2″	1369
Ditto	,,	1456
African Oak	,,	1425
Ditto	,,	1447
Ditto	,,	1873
Ditto	,,	1968
Yellow Dantzic Fir	,,	999
English Oak	1″ × 1″	160
Ditto	,,	168
Ditto	,,	193
African Oak	,,	202
Ditto	,,	224
Ditto	,,	224
Yellow Dantzic Fir	,,	118

The above and the following experiments, communicated by this eminent engineer, were made during the year 1817 and subsequently, and being almost entirely new to the profession, are valuable for their novelty, and particularly for the light they will afford the student and practical man in application of strength, where before all was darkness.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 2.

On the Tensile Strength of various Timbers per square inch.

	lbs.		lbs.
Ash	12,000	American Oak .	12,200
Beech	10,500	English Oak . .	12,000 to 10,500
Elm	10,000	Riga Oak . . .	12,000
Yellow Fir	9,600	African Oak, from	15,600 to 14,000
White Deal	10,000		

No. 3.

On the Tensile Strength of different Metals per quarter of an inch square.

	Tensile force in lbs.	Force in tons pr. square inch.
Cast Iron, horizontal	1166	8.0*
Cast Iron, vertical	1218	
Cast Steel, tilted	8391	59.94
Blister Steel, reduced per hammer	8322	59.44
Shear Steel, ditto	7977	52.50
Swedish Iron, ditto	4504	32.17
English Iron, ditto	3492	24.94
Brass-hard Gun metal (2 trials)'.	2273	16.23
Wrought Copper, reduced per hammer . .	2112	15.08
Cast Copper	1192	8.06
Fine yellow Brass	1123	8.00
Cast Tin	296	1.60
Cast Lead	114	0.81

* These were unusually strong specimens, but the average of subsequent experiments on various Irons does not give more than 6½ tons per square inch.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 4.

On the Transverse Strength of Cast Iron Beams, for the purpose of determining the effect of Wrought Iron, when mixed with Cold Blast Blaenarvon Cast Iron in different proportions.

Quality of iron, No. 1, Blaenarvon, unmixed with wrought iron. 4 ft. 6 in. long between supports, and 1 in. square.

Three bars experimented upon, the average weight of each being 16 lbs. 5 oz.

Average deflection with 506 lbs. in scale, 1.76 in.
Breaking weight . . 511 lbs.

Three bars of similar dimensions to the above, with 10 per cent. of wrought iron, and weighing upon an average 16 lbs. 9 oz. each;

Average deflection with 611 lbs., 1.50 in.
Breaking weight . . 625 lbs.

Three bars of similar dimensions to the above, mixed with 20 per cent. of wrought iron, and weighing upon an average 16 lbs. 10 oz. each:

Average deflection with 628 lbs., 1.58 in.
Breaking weight . . 672 lbs.

The results are, that 10 per cent. wrought iron, with No. 1 Blaenarvon cast iron, gives an additional strength of 22½ per cent, and with 20 per cent. wrought iron an additional strength of 31½ per cent.

Similar Experiments were made with bars of Blaenarvon Cast Iron, mixed with 30, 40, *and* 50 *per cent. of Wrought Iron respectively.*

The results were—

For 30 per cent. wrought iron, an increase in the strength of the bar of . . . . 60 per cent.
For 40 per cent. wrought iron, an increase of . . 33 „
For 50 ditto ditto . . 26½ „

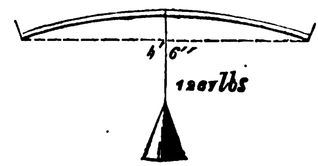
From which it appears that 30 per cent. of wrought iron, mixed with the Blaenarvon, gives the greatest strength.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

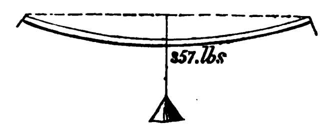
No. 5.

On the Comparative Strength of similar bars of Blaenarvon Cold Blast Iron in different positions,* 1 *in. square.

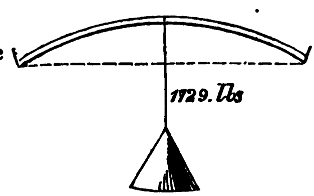
No. 1. In the form of an arch, 4 ft. 6 in. between the abutments; rise or versed sine $\frac{1}{18}$ of chord or span, bore . . . . . .



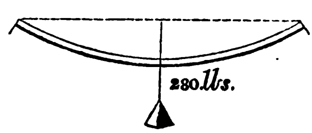
No. 2. A bar, similar in every respect, but the arch inverted, bore . . . .
and was therefore $3\frac{1}{4}$ times weaker than the former arched beam.



No. 3. The same with versed sine $\frac{1}{8}$ of chord or span, bore for the mean of 2 experiments . . .
from whence it appears that the bar in this last position was 3.6 times stronger than the straight bar, and 5 times stronger than the bar in the form of an inverted arch of $\frac{1}{18}$ rise.



No. 4. Same as above, but reversed.



EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 6.

On the Transverse Strength of Bars of Blaenarvon Iron, of different Forms, Depths and Thicknesses, but of equal Weight with Bars of 1 *in. square, or of* 16 *lbs. to* 17 *lbs. each.*

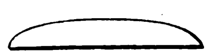
Rectangular Bars.

Distance between supports. ft.	in.	Weight of Bars in lbs.	Depth. in.	Thickness. in.	Breaking Weight in lbs.
4	6	16½	2	½	1121
4	6	16, 10 oz.	3	⅓	1568
4	6	17	4	¼	2352

Upper side of bar Parabolic.

4	6	11	2	½	953
4	6	11	3	⅓	1429

Upper side of bar Semi-Elliptical.



4	6	12	2	½	950
4	6	12	3	⅓	1450

The permanent deflection varies from ⅓ to ½ of the breaking weight.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 7.

On the crushing of Stones, 2 *specimens of each.*

Side of cube in inches	Designation.	Specific Gravity.	Crushing Weight in lbs.	Crushing Weight per cubic inch in lbs.
2	Anglesea Granite . . .	2.704	29637	3692
2	Blackburn ditto	2.441	19400	2425
2	Manley ditto	2.454	10900	1362
2	Talacre ditto	2.419	18950	2368
2	Anglesea ditto (4 specimens)	2.708	23632	2954
	Tamur ditto	2.650	23425	2928
	Ditto ditto (fine grained)	3.050	24125	3015
	Cornish Heytor (split) . .		30912	3864
	Ditto ditto (crushed) .		46144	5768
$1\frac{1}{2}$	Dartmoor, (10 specimens) supported without fracture	2.626	18480	
2	Dartmoor, (5 specimens) .	2.626	37408	4676

The force required to crush a cubic inch of Cast Iron is 70 tons.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 8.

On Granite from different Quarries.

Name of Quarries.	Length.	Breadth.	Thick-ness.	Area.	Weight in air.	Weight in Water.	Specific Gravity.	Average Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Real weight supported.				Weight supported per square inch.		
	in.	in.	in.	in.	grains.	grains.			lbs.		tns.	cwt.	qrs.	lbs.	cwt.	qrs.	lbs.
Anglesea	2	2	2.02	4	5474.5	3448	27014	27049	169	13.25	13	4	2	13	63	3	22
Do.	2	1.97	2.04	3.94	5518.5	3481	27084										
Blackburn	2.04	2.03	2.04	4.14	4891.5	2888	24414	24324	152	14.73	8	13	0	24	44	1	19
Do.	2.03	2.03	2.00	4.12	4768.5	2805	24234										
Manley	2.02	2.0	2	4.6	4401	2441	22454	22567	141	15.88	4	17	1	8	24	1	9
Do.	2.0	2.0	2.0	4.0	4097	2295	22680										
Talacre	2	1.97	2	3.94	4636	2720	24196	24140	150.87	14.84	8	9	0	22	42	1	5
Do.	1.98	1.98	2.02	3.92	4694	2745	24084										
Anglesea	1.75	1.5	1.42	2.62	. .	. .	. .	. .	169.25	13.23	8	17	3	17	67	3	2
Do.	1.75	1.5	1.40	2.60	. .	. .	. .	. .	169.25	13.23	11	14	1	9	89	0	22
Do.	1.75	1.5	1.4	2.62	2555	1611.5	27080	. .	169.25	13.23	13	11	2	17	103	1	26
Do.	1.75	1.5	1.45	2.62	2611	1647	27085	. .	169.25	13.23	7	19	0	17	60	2	14
Tamor Granite . .	2.02	2.02	1.91	4.08	5338.5	3324	26500	. .	165.52	13.52	10	9	0	17	51	1	1
Do. Fine Grained .	1.53	1.43	1.36	2.18	1959	1320	30500	. .	190.62	11.750	10	15	1	17	100	0	2
	Average of 10 Specimens of Dartmoor Granite, cubes 1½ each								. .	.	8	7	2	,,	71	2	18
	Ditto 5 do. do. do. cubes 2 each								. .	.	16	18	3	,,	84	2	21

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 9.

An account of Experiments made on the powers of Stones to resist pressure, previously to the construction of New London Bridge.

No. of Experiment.	Dimensions of cube.	Name of Granite.	Crushing Weight.				Crushing Weight in lbs.
	in.		tns.	cwt.	qrs.	lbs.	
1	$1\frac{1}{2}$	Craig Leith Freestone (white) .	4	2	3	19	9287
2	,,	Dundee do. (dull grey)	5	3	0	24	11560
3	,,	Heytor Granite	6	9	0	24	14448
4	,,	Aberdeen, fine grained (yellow and grey)	5	3	0	24	11560
5	,,	Do. do.	6	15	2	12	15188
6	,,	Do. do. (time 4 hours)	5	13	2	1	12657
7	,,	Do. do. inclining to blue	6	3	3	10	13870
8	,,	Peterhead (coarse red)	6	4	2	23	13967
9	,,	Do. Granite . , . . .	7	7	3	12	16560
10	,,	Do. fine grained, (reddish)	6	8	0	24	14360
11	,,	Do. blue kind	7	8	2	$12\frac{1}{2}$	$16644\frac{1}{2}$
12	,,	Jersey do. duration of Experiment 50 hours (blue)	6	11	3	22	14778
13	,,	Guernsey, (2 specimens) Granite	10	7	3	12	23280
14	,,	Cornish, large grained (light grey)	6	12	3	7	14857
15	,,	Heytor Granite (another specimen)	11	2	3	7	24864
16	,,	Sienite	6	13	0	24	14920
17	,,	Do. (2 specimens) . . .	13	7	0	24	29904
18	,,	Aberdeen Granite (red) . . .	7	3	3	24	16100
19	,,	Do. do.	8	12	2	24	19320
20	,,	Do. do. full grained (red)	7	3	3	24	16100
21	,,	Do. do.	8	17	3	12	19920

Average duration of Experiments 10 hours.

A cubic foot of Granite, allowing for every variation, is capable of sustaining a pressure of from 600 to 700 tons, a stress far beyond anything that can ensue in the boldest arch.

The arches of New London Bridge onl give a pressure from 80 to 90 tons per cubic foo

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

Weights and Dimensions of Arches of London Bridge.

	Superficial Area.	Solidity.	Tons Weight.
Land Arches	625	30.000	2097.98
Second Arches	785	37.680	2634.99
Middle Arch	930	44.640	3121.68

Angles at which the dressed Voussoirs commenced sliding
without mortar . . . . 33.30°
Do. with mortar fresh laid . . . . . 25.30°

Angles at which various substances stand when dry—

Fine flour	44°	Sand	32° to 33
Wheat, Barley . .	26.44°	Coarse Gravel .	35°
Peas	24°	Fine do. .	33°

These experiments on the angles repose of voussoirs made by our distinguished bridge builder, are particularly valuable, and still more from the important work in which they were noted. Rondelet, Art de Batir, Vol. IV. p. 273, says, "*It* has been found from experiments, that hard stones laid dry commenced slipping at an angle of 30 degrees, and with mortar fresh laid at angles of 34 and 36 degrees ; and with soft stones on mortar fresh laid 45 degrees, when the centre of gravity does not fall without the base." From 34 to 36 degrees is repeated by Tredgold in Professor Barlow's edition.

EXPERIMENTS BY GEORGE RENNIE, Esq.—*Continued.*

No. 10.

ANGLES of EQUILIBRIUM at which various substances stand as taken with a Clinometer.

		Degrees.
Lime dust as it falls from a spout		45
Wheat Flour	do.	44
Malt do.	do.	40
Saw Dust	do.	44
Dry Sand	do.	40
Do. less dry	do.	39.16
Wheat Corn, unground	do.	37
Malt do. do.	do.	37
Common Mould	do.	37
Peas	do.	35
Wet Thames Gravel		35 to 36
Dry Quick Sand from River Thames		35
Wet do. do.		40
Coarse Gravel Heaps		35 to 38
Common Gravel		35 to 36
Large Flints		40 to 45
Do. half the size		35
Do. approaching to sand		34 to 35

CHAPTER VI.

EAST ANGLIAN RAILWAYS.—ELY LINE.

Specification of Bridge over the River Ouse at Hilgay.

J. S. VALENTINE, Esq., C.E.

The foundations for the piers shall be excavated to the depths and widths shown upon the drawings, or as much lower as the engineer may consider necessary from the nature of the ground.

Previous to commencing the foundations, the bottom of the trenches shall be made perfectly dry and level, for the reception of the planking.

The space around the foundations, to the height of the present surface of the bed of the river, shall be filled in with sound gault, as the work proceeds, and well rammed in layers not exceeding 6 inches in thickness.

Stone.

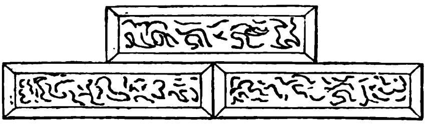
The whole of the stone to be used in the piers shall be from Bramley Fall Quarries, and of the size shown upon the drawings, and each stone shall be laid upon its natural bed.

The size and bond of the stone in each course are shown with blue and brown lines in drawing No. 6 *d*, and this method of laying the work must be strictly adhered to.

The face of the stone-work from the surface of the planking to within 4 inches of the ground line, shall be rough quarry scappled with the beds and vertical joints truly worked. Each

of the footings shall be in one thickness of stone, and each course shall not have less than three bonding stones.

The courses marked in the drawings Nos. 6 *a*, 6 *b*, shall be finished with their own natural face, and each stone shall have a tooled margin, worked round the edge 1¾ inches wide,

thus, 

The curved part of each of the courses shall be roughly picked and finished with its own natural face, and each stone shall have a tooled margin as before described. The courses, marked A and C on the aforesaid drawings, shall be neatly tooled, care being taken that the stroke shall be in the direction of the weather current, and not less than seven strokes in an inch. The centre string and the upper facia shall be weather throated. The springing course shall be doweled together with slate plugs, 7″ × 3″ × 3″, as shown upon the drawing. Two copper cramps in each joint of the last named course shall also be inserted and securely let in with lead.

The cast iron shoes for the reception of the ends of the bows, shall have their flanges let flush into the cap stones of the piers. They shall be bedded on lead, and bolted down in the manner shown on the drawing, and when fixed, the joints round the edges shall be well caulked with lead.

All the beds and joints of the piers below the ground line shall be made close, and well flushed in with strong lime grout. The joints above the ground line shall also be worked close, and shall be laid and neatly pointed with fine beaten mortar. All bolts and iron work shall be properly fixed in the manner shown upon the drawings. The lime to be used shall be fresh burnt and of the best quality of water lime from Stoke or Isleham, or such other place as shall be approved by the engineer.

The piers shall, at the completion of the bridge, be neatly and truly cleaned down, and finished entirely to the satisfaction of the engineer.

Carpentry.

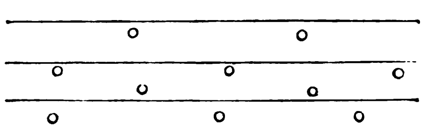
All the timber to be used for these works shall be the very best Memel or Dantzic fir, free from sap and shakes, large and loose knots, or any other defects, and shall hold when finished, the several scantlings figured on the drawings, and be framed together in the manner thereon denoted, and the whole of the works shall be executed in accordance with the Specification for timber bridges generally, hereinafter written.

The arched ribs shall be made to the proper radius. The two outside ribs shall be three feet eight inches, by two feet two inches, and the centre rib three feet eight inches, by two feet nine inches, they shall be formed with Dantzic deals, dressed on the sides and edges, and in the longest lengths which can be procured. These deals shall be of the very best quality, perfectly sound and well seasoned, and they shall be submitted to the engineer, and approved by him, before they are used in the work.

Each deal shall be bent over the one below it, in such a manner as to break joint alternately both ways, and no two end joints shall come over each other, or within three feet of the joint below it. The first course shall be three deals in width, and the next two whole deals and two half deals, and so on till the rib is formed. Each course of deals shall be covered with a coating of marine glue which shall be applied hot, and in such manner as the engineer shall direct.

The whole of the deals shall be fastened together with the best compressed oak-trenails one inch in diameter, made by Messrs. Ransome and May, of Ipswich, which shall be placed four feet apart:—

thus,



each trenail shall be of sufficient length to pass through three deals, and each course shall be trenailed to the two under courses.

The greatest care must be taken in fitting the ends of the deals to the abutment plates, that they fit perfectly close, and true on their ends, and the ends of all the planks shall abut perfectly square, and true upon each other throughout the bow.

The longitudinal beams shall be of the lengths shown upon the drawings, No. 6 *c*, and scarfed together in the manner shown on drawing No. 6 *f*. The surface of the beams which are bolted together, shall be wrought perfectly true, and a coating of marine glue shall be laid between them in the manner described for the bows. The whole of the diagonal braces shall be accurately cut to the exact length, and carefully fitted into the iron shoes.

The joists for the roadway shall be 12 inches by 9 inches, and they shall be each of them in one length, and extend across the whole of the longitudinal beams, upon which they shall be notched, and bolted down in the manner shown upon the drawing, and the ends shall be neatly finished to such form as shall be directed. The bearers for the rails shall be 12 inches by 6 inches, bolted to the joists in the manner shown upon the drawing, the space between the bearers shall be laid with Dantzic deals 11 inches by 3 inches, spiked to the transverse beams with spikes 7 inches long, and ½ inch in diameter, there shall be two spikes at each joist, and four at the heading joists, and no two heading joists shall come together on the same joist.

The towing path shall be carried under the centre opening of the bridge, on cast iron brackets in the manner shown upon the drawings.

The viaduct at each end shall be built in the manner shown upon the drawings, and of such dimensions as are there given.

Iron Work.

The whole of the iron to be used in this viaduct shall be of the very best quality.

Previous to the order for the iron work being given, the engineer shall certify his approval of the foundry for the castings, and also the manufacturer of the whole of the wrought iron work. The castings shall be made perfectly true, and of the exact size and dimensions shown on the drawings. The suspension rods for the platform, together with the whole of the bolts, straps, spikes, &c., shall be of the very best quality of scrap iron, and of the dimensions shown upon the drawings, and each suspension rod shall be tested to a weight of 20 tons. The thread of the screws of all the bolts shall be engine cut, and of the very best description of workmanship, which shall have been submitted to and approved by the engineer, and all bolts which have screws not cut perfectly clean and true, will be at once rejected.

The greatest possible care shall be taken that the heads of all the bolts shall be perfectly sound and true, and of the full dimensions shown on the drawings. All the iron to be used in this bridge shall be heated to about a blue heat, and the surface then struck over with raw and linseed oil to prevent rust.

The contractor must take upon himself the entire responsibility of the whole of the works during their erection, and must at his own expense erect good and substantial coffer dams, for the purpose of getting in the foundations of the piers which shall effectually keep out the water from the foundations, during the time of their erection, and after the completion of the work, the piles used in forming the coffer dams, shall not be drawn, but shall be cut off at the level of the bed of the river, if not otherwise directed by the engineer. All piles which may be used for the purpose of scaffolding or other temporary works shall be drawn upon the completion of the works.

The bed of the river shall be excavated to the depth shown

upon the drawings, and to such extent, and in such manner as is stated in the Act of Parliament for this Railway.

And the barrier banks on each side of the river shall also be strengthened in accordance with the Act of Parliament. During the execution of the work the contractor shall not in any way obstruct or impede the navigation of the river or the towing paths thereof, but shall in all respects comply with the several clauses in the Lynn and Ely Railway Act, for the preservation of the Drainage and Navigation of the Bedford Level, and all other clauses relating to this river. And he shall also be responsible to the engineer who may be appointed by the corporation of the Bedford Level to superintend the Works, for the due and proper performance of such works, and for complying with the several clauses above referred to.

CHAPTER VII.

TABLE

OF SPECIFIC GRAVITIES, WEIGHT PER CUBIC FOOT, AND CUBIC FEET PER TON, OF MATERIALS,

With Cohesive Strength, and Constants of Elasticity and Transverse Strength. The authorities are G. Rennie, Esq.; T. Tredgold; Professor Barlow; J. Bramah; Rondelet, and the Report of the Commissioners appointed for examining the different quarries in England, &c. &c.

TABLE OF SPECIFIC GRAVITIES, &c.

Name of Material.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Cohesion in lbs. per square inch. Pressure.	Constant of Elasticity.	Const. of Transv. Strength	Remarks.
Acacia	.710	44.37	. .	. .	. .	144000, or 83	1860	Average height of trunk 12 feet, average diameter 11 inches.
Do.	.791	49.43						
Air	.0012	.075						
Alder	.555	34.68	64.58					
Ash	.758	47.37	47.28	15000				
Do. dry heart-wood	.845	52.81	42.51		. .	205000, or 113	2020	This timber is little used in carpentry, and unless constantly and perfectly dry decays rapidly; it is in great demand among wheelwrights; the total height of the tree averages 60 and 70 feet.
Basalt	3.000	187.50						
Do.	2.478	154.87						
Beech	.854	53.37	41.95	. .	. .	. .	. .	
Do.	.720	45.00	49.77	11000	. .	169200, or 92	1560	Beech is very durable if kept constantly *wet*, and being also hard, forms excellent piling; in building it is not much used; the average height of the trunk is 45 ft., and the average diameter $2\frac{1}{3}$ ft.
Do.	.696	43.50	52.18	. .	. .			
Birch	.720	45.00	. .	. .	. .	205000, or 113	1928	Birch and Alder are both suitable for hydraulic works, but both decay easily if exposed to damp, and therefore they are unsuitable to carpentry.
Do.	.792	49.50	45.25	. .	. .			
Bismuth	9.822	613.87	3.64					
Boxwood, from	.949	59.31	. .	19000				
Do. to	1.328	83.00	. .					

Brass, cast	8.396	524.80	. .	18000	82000			
Do. wire	8.544	534.00	. .					
Brickwork (new)	1.872	117.00						
Do. (old)	1.520	95.00	. .	. .	. .	. .	3939 to 5115	Professor Barlow gives these numbers as the cohesive power of bricks, (supposing the calculations made by the same formula as for timber). One cubic yard of brickwork in cement, may be calculated to weigh about 3284 lbs. and in mortar 2996 lbs. The crushing weight on pale red brick, or rather soft, is 500 lbs., on hard red, 807 lbs., on fire-brick about 1710 per square inch.
Do. in cement	1.920	120.00						
Red Brick	2.160	135.00						
Do. common (about)	1.760	110.00						
Do. London stock	1.840	115.00						
Do. Welsh fire	2.408	150.50						
Chalk	2.315	144.68	15.41	. .	500			
Do.	2.656	166.00	13.49					
Do. Dorking	1.872	117.00	19.14					
Cedar (Indian)	1.315	82.18	. .	500				
Do. from	.453	28.31	. .					
to	.753	47.06						
Cement	1.600	100.00	22.40	. .	. .	. .	. .	The adhesive power of good cement, when the power tending to rupture is parallel to the joint, is about 500 lbs. per square inch.
Clay, from	1.920	120.00	18.66					
to	2.160	135.00	16.59					
Chestnut (sweet)	.696	43.50	. .	1200	. .	. .	. .	This timber was much used some centuries since, and is very durable if properly used; the roof of Westminster Hall and that of King's College, Cambridge, are constructed with Chestnut. Average height of trunk, 40 ft., average diameter 2 ft.
Coke	.755	47.00						
Coal, Glasgow	1.286	80.30	. .	. .	. .	. .	. .	The relative heating powers of different coals have been proportioned as follows:—
Do. Kilkenny	1.526	95.30						
Do. Jarrow, Newcastle	1.266	79.10						

TABLE OF SPECIFIC GRAVITIES, &c.—*Continued.*

NAME OF MATERIAL.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch.		Constant of Elasticity.	Const. of Transv. Strength	REMARKS.
				Tension.	Pressure.			
Coal, Garesfield, do.	1.280	80.00						lbs. of water heated from 32° to 212°. *Name of coal.*
Do. Wigham Banks, do.	1.302	81.37						72.0 ...... Dowlas in Wales.
Do. Wigan, Lancashire	1.319	82.43						70.0 ...... Newcastle.
Do. Cannel Coal, do.	1.272	79.50						56.4 ...... Cannel, Glasgow.
Copper, cast . .	8.800	550.00	. .	19000	57000			64.1 ...... „ Wigan, Lancashire.
Do. wrought .	8.915	557.20	. .	33000	51000			
Do. wire . .	8.880	555.00						53.2 ...... „ Lancashire.
Earth, from . .	1.520	95.00	23.57					
to . .	2.016	126.00	17.77					
Ebony, American .	1.328	83.00						
Do. Indian	1.216	76.00						
Elm . . .	.553	34.56	64.93	. .	1200	87400, or 50	1010	The Elm is seldom used in building, but is noted for its durability under water; it was used for the piles of Old London Bridge; average height of trunk 44ft., and diameter 2ft. 8 in.
Do. . . .	.543	33.93	66.01	. .	. .	92750, or 54	1118	
Fir, Christiana .	.688	43.00	52.09	. .	. .	198700, or 115	1562	There are two sorts of fir, red or yellow, and white; the red is the most durable in any situation, and the best of this kind is generally from Norway: it is imported in logs and
Do. Norway . .	.577	36.06	62.09	. .	. .	182000, or 105	1470	
Do. Memel . .	.590	36.87	53.	. .	. .	200000, or 115	1730	
Do. American .	.553	34.56	64.71	9500	1800	274000, or 158	1100	
Do. Riga . .	.738	46.12	48.56	. .	. .	124000, or 71	1050	

Fir, Scotch . .	.693	43.31	51.72	. .	. .	108700, or 62	1262	deals; the tree (Pinus Sylvestris) seldom exceeds 18 in. in diameter from Norway, and 2 ft. from Russia. White Fir (Pinus Abies) is imported from Christiana in planks and deals, and also from America. It was said by Brindley that Red Riga would last as long as oak in any situation.
Glass, from . .	2.824	187.00						
to . .	2.520	157.50						
Granite, Aberdeen red	2.643	165.20	13.55	. .	7100	. .	. .	The numbers under the column "pressure" are from experiments by G. Rennie, Esq. and the late J. Bramah, Esq. *a* are the pounds borne, × the pounds which fractured, and the others the pounds which crushed the specimens.
Do. × do. blue	2.608	163.00	13.73	. .	9200 ×			
Do. do. gray	2.664	166.50	13.45	. .	6700			
Do. Anglesea .	2.704	169.00	13.25	. .	7162 *a*			
Do. do. *a* .	2.708	169.25	13.23	. .	11590			
Do. do. *a* .	2.708	169.25	13.23	. .	9990			
Do. do. *a* .	2.708	169.25	13.23	. .	6790			
Do. Blackburn *a* .	2.432	152.	14.73	. .	4975			
Do, Manley *a* .	2.256	141.	15.88	. .	2715			
Do. Tamor *a* . .	2.649	165.62	13.23	. .	5741			
Do. do. *a* fine grained Specimen *a* .	3.049	190.62	11.75	. .	11200			
Do. × Dartmoor	2.664	166.50	13.45	. .	7800 ×			
Do. Guernsey .	2.999	187.47	11.96	. .	10300 *a*			
Do. × Heytor .	2.555	159.75	14.02	. .	8700 ×			
Do. Talacre .	2.401	150.80	14.85	. .	4700 *a*			
Do. × Penryn .	2.736	171.00	13.10	. .	5700 ×			
Do. Peterhead .	2.432	152.00	14.73	. .	7600			
Gravel . . .	1.760	110.00						
Indigo . . .	.769	48.10						

Table of Specific Gravities, &c.—*Continued.*

Name of Material.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Cohesion in lbs. per square inch. Pressure.	Constant of Elasticity.	Const. of Transv. Strength	Remarks.
Iron, cast . .	7.104	444.00	5.04	19000	14560	2252000, or	7600*a*	*a* These constants will of course be understood to apply to *rectangular* bars.
Do. Native . .	6.723	420.18	5.33	. .	. .	. .	. .	According to Duleau, wrought iron may be extended to $\frac{1}{3333}$ of its length without injuring its elasticity. Lavoisier and Laplace found by experiments that wrought iron at 32° measuring 1. expanded at 212° to 1.00122048; Smeaton found 1.001258. For cast iron, General Boy found 1.0011094.
Do. bar . .	7.600	475.	4.71					
Do. bar. . .	7.787	486.70	4.27	56000	. .	1303 *a*		
Do. do. . .	. .	. .	. .	67600				
Do. Swedish . .	. .	. .	. .	72000				
Do. Wire . .	. .	. .	. .	78000				
Ivory . . .	1.825	114.10						
Larch . . .	.522	32.62	68.66	. .	. .	112000, or 65	832	Larch is a valuable timber, being strong, hard, and durable; it has in all ages been much esteemed, and is one of the best for hydraulic works; it is said that the ancient city of Ravenna was entirely founded on larch piling; there is no doubt that it is admirably adopted for the construction of wooden bridges and viaducts, but it has not as yet been much used
Do. . . .	.560	35.00	64.	. .	. .	131600, or 76	1149	

Lead, cast . .	11.352	709.50	3.15	1782				for this purpose, having but lately been grown to any extent in Britain; it bears exceeding well the driving of bolts and spikes; every one knows how commonly it is used for railway sleepers. *thick* *lbs.* One ft. super. milled lead $\frac{1}{16} = 3.71$ " " $\frac{1}{12} = 4.95$ " " $\frac{1}{10} = 5.93$ " " $\frac{1}{8} = 7.41$ " " $\frac{1}{6} = 9.9$ " " $\frac{1}{4} = 14.85$ $32\frac{1}{11}$ feet cube of lime = one hundred of lime, containing 25 bushels, and the measure is 3 feet square, and $3\frac{1}{2}$ deep.
Do. milled . .	11.407	712.93	3.14					
Lime . . .	.843	52.68	42.52					
Limestone, from .	1.856	116.00	. .	. .	17300 on compact specimens.	. .	. .	Generally according to Smeaton, those limestones into which clay enters as a component are the best adapted for hydraulic works.
Do. . . .	2.536	158.50	. .	. .				
Do. Beerquarry, Devon	2.108	131.75	17.	. .	. .	. .	. .	Light brown; friable; chiefly carbonate of lime; 6 × 3 × 2.
Do. Chilmarks, Wilts.	2.457	153.58	14.58	. .	10080	. .	. .	Light greenish brown; carbonate of lime with a proportion of silica; blocks from 10 cwt. to 3 tons; Salisbury Cathedral and Wilton Abbey; generally in excellent condition; prices at quarry 1*s*. 6*d*. to 2*s*. per cub. foot; in London 4*s*. 10*d*. to 5*s*. 4*d*.

TABLE OF SPECIFIC GRAVITIES, &c.—*Continued.*

NAME OF MATERIAL.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Cohesion in lbs. per square inch. Pressure.	Constant of Elasticity.	Const. of Transv. Strength	REMARKS.
Do. Hopton Wood, Derbyshire . .	2.536	158.50	14.08	. .	. .	. .	. .	Warm grey; compact; carbonate of lime; blocks of 100 ft. cube varying in depth from 3 ft. to 10 ft.; Belvoir Castle, Chatsworth, Drayton Manor; at quarry 3*s*. to 4*s*. per cubic foot: in London, 4*s*. 10*d*. to 5*s*. 10*d*.
Do. Seacombe, Dorset.	2.416	151.00	14.83	. .	. .	. .	. .	Light brown; semi-compact carbonate of lime; 6 × 2 and 4 × 3. Lighthouses, piers and docks; 1*s*. $2\frac{1}{4}d$. at quarry per cubic ft.; London 1*s*. $9\frac{1}{4}d$.
Do. Sutton, Glamorganshire . .	2.176	136.00	16.47	. .	. .	. .	. .	Light creamy; compact and highly crystallized carbonate of lime; blocks of 6 tons and upwards; thickest bed 12 ft. In many ancient buildings in Glamorganshire and the adjacent counties.
Mahogany (Spanish)	.852	53.00						
Do. Honduras	.560	35.00						
Marble, White, fine grained, compact .	2.840	177.50	. .	. .	9680			
Do. white . .	2.720	170.00	. .	. .	6058			
Do. mercury (fluid) .	13.568	848.00	2.641					
Mortar, from (old) .	1.414	88.37						
to (new) .	1.903	118.93						
Magnesian Limestone, Bolsolver, Derbysh.	2.427	151.70	14.76	. .	. .	. .	. .	Light yellowish brown; Southwell

							Church, &c., price per cubic foot at quarry 10*d.*; in London 2*s.*; for large blocks in London, 4*s.* has been paid; beds from 8 in. to 2 ft. thick; but thicker may be obtained.
Do. Brodsworth, Doncaster, Yorkshire	2.138	133.63	16.76	. .	. .	. .	. . Light brown; Doncaster Old Church; Mansion House; thickest bed 3 ft. 6 in.
Do. Cadeley, Doncaster, Yorkshire .	2.025	126.60	17.69	. .	. .	.	. . Day and Martin's, Holborn; cream colour; the central beds, which are the best, are 4 ft. thick; price in London 1*s.* 10*d.* per cubic foot.
Do. Huddlestone, Sherburne, Yorksh.	2.205	137.68	16.20	. .	6832	. .	. . Light cream, York Minster, Selby Cathedral, Westminster Hall; may be obtained 4 ft. thick, 2*s.* at quarry; 3*s.* in London per cubic foot.
Do. Parknook, Yorks.	2.140	133.75	16.75				
Do. Roach Abbey, Bawtry, Yorkshire	2.225	139.12	16.10	. .	6170	. .	. . Whitish cream; very numerous ancient and modern buildings; this stone vegetates very rapidly; it is liable to stun under the tool; thickest bed 2 ft. 6 in.; 8*d.* to 1*s.* 6*d.* at quarry; 2*s.* 1½*d.* to 2*s.* 11½*d.* in London.
Do. Smawse Tadcaster Yorkshire .	2.040	127.50	17.56	. .	. .	. .	. . Light yellow brown; York Minster, Beverley Minister, Ripon Minster, &c.; largest blocks 8′ × 3′ × 30′, 7*d.* at quarry; 2*s.* 1½*d.* in London. "The nearer the magnesian limestones approach to equivalent pro-

TABLE OF SPECIFIC GRAVITIES, &c.—*Continued.*

NAME OF MATERIAL.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch.		Constant of Elasticity.	Const. of Transv. Strength	REMARKS.
				Tension.	Pressure.			
								portions of carbonate of lime, and carbonate of magnesia, the more crystalline, and the better they are in every respect." Hydraulic lime is prepared from the magnesian limestone.
Oak, fast grown	.937	58.56	38.25	. .	. .	193000, or 111	1560	Loose fibred, porous oak is of inferior quality; choose close grained, heavy, and fine pored specimens: it is principally used where timber is submitted to compression, and is in these days more in use for ship building than constructive purposes.
Do. slow grown	.846	52.87	42.36	. .	. .	104000, or 60	1265	
Do.	.969	60.56	36.98	11000	3800	109000, or 63	1180	
Do. Canada	.872	54.50	. .	. .	. .	268000, or 155	1760	
Do. Dantzic	.756	47.25	47.40	. .	. .	148000, or 86	1450	
Do. African	.993	62.06	. .	14000	. .	299500	2570	
Oolitic Stones, from	2.362	147.66						
to	1.968	123.00						
Do. Ancaster Quarry, Lincolnshire	2.228	139.25	16.08	. .	33	. .	. .	Cream colour; fine grained and compact; Wollaston Hall, and Belvoir Castle; blocks of 3 and 5 tons in 18 in. thickness, price 9*d.* to 1*s.* 6*d.* at quarry; 1*s.* 10*d.* to 2*s.* 7*d.* in London.
Do. Barnack Mill, Northamptonshire	2.188	136.75	16.38	. .	25	. .	. .	Whitish brown; often coarsely lami-

—Bath Lodge Hill, Somerset. . .	1.856	116.00						nated; Peterborough Cathedral, and Croyland Abbey, &c.; beds up to 18 in. thick; 1*s.* at quarry; 2*s.* in London, per cubic foot.
—Bath, Baynton, Somerset. . .	1.968	123.00	18.21	. .	. .	. .	. .	The price of Bath is given at 6*d.* and 7*d.* at quarry: 1*s.* 10*d.* and 1*s.* 11*d.* in London. Its real value is well known.
—Drew's Quarry (Bath), Somerset.	1.961	122.62	18.26					
—Cranmore, Wilts.	2.148	134.25	. .	. .	. .	. .	. .	Light brown; Wells Cathedral; beds 20 in. thick; 7*d.* at quarry.
—Haydor, Lincolnshire . .	2.134	133.42	16.78	. .	. .	. .	. .	Dark cream colour; Lincoln Cathedral; blocks 14′ × 3′ × 4′; 8*d.* at quarry; 2*s.* 4*d.* in London.
—Ketton, Rutlandshire . .	2.053	128.33	17.45	. .	4000	. .	. .	A good lasting stone, much used in ancient and modern buildings dark cream colour; the rag stone, 3 ft. 6 in. thick; 1*s.* 9*d.* at quarry; 3*s.* 4*d.* in London.
— Vern Street Quarry, Portland.	2.153	134.62	. .	. .	. .	. .	. .	Whitish brown; may be obtained of any practicable size; this stone has been employed in various public buildings: price per cubic foot at quarry 1*s.* 4½*d.*; in London 2*s.* 3*d.*
— Grove Quarry, Bowes, Portland .	2.361	147.62 best	. .	. .	6000	. .	. .	An oolitic carbonate of lime, with numerous fragments of shells; whitish brown; may be had 9 ft. thick; the lower bed is the best. St. Paul's Cathedral; 1*s.* 4½*d.* per cubic ft. at quarry.

1

Table of Specific Gravities, &c.—*Continued.*

Name of Material.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch.		Constant of Elasticity.	Const. of Transv. Strength	Remarks.
				Tension.	Pressure.			
——Waycroft Quarries, Portland .	2.168	135.50	. .	. .	. .			Oolitic carbonate of lime, with fragments of shells; whitish brown; depth of freestone 13 ft.; Goldsmiths' Hall and Reform Club House; 1*s.* 4½*d.* per cubic foot at quarry.
——Goslings Quarry, Portland . .	2.028	126.80 Roach	. .	.	. .			Any practicable size, and the same remarks as above. There are 56 quarries in the Island of Portland, and about 24,000 tons are annually consumed; the top best is generally the best stone, being fine grained, and free from defects; in the bottom beds the stone is ill cemented, and does not stand the weather; in the east cliff quarries the stone is harder than in the west cliff. Besides the buildings already mentioned, Somerset House, St. Martin's-in-the-Fields, and St. Margaret's Tower, Lothbury, are built of Portland stone; Westminster bridge, and, we believe, Blackfriars, are constructed of Portland stone; but it is not a lasting material for hydraulic works. The oolitic formation consists of three strata, three times repeated; the stone is mostly a carbonate of lime, with shelly fragments, cemented together by a calcareous and often argillaceous cement; this bed rests upon one of argillaceous sand and sandstone, which reposes on a thick deposit of clay.

—— Taynton, Oxon.	2.147	135.93	15.74	. .	. .	. .	. .	Brown; thickest bed 7ft.; Blenheim, and interior of St. Paul's; 10*d.* at quarry; 2*s.* 4*d.* in London.
Peat from . .	1.008	63.00						
to . .	1.472	92.00						
Pebble . . .	2.600	163.00						
Pewter . . .	7.248	453.00						
Pine, Pitch . .	.660	41.25	. .	. .	. .	153000, or 88	1630	
Pine, Red . .	.657	41.06	. .	. .	. .	23000, or 133	1341	
Sand from . .	1.440	90.000						
to . .	1.872	117.00						
Sandstone from .	1.648	103.06	. .	. .	. .			
to .	2.687	167.94						
—— Abercarne, Monmouthshire . .	2.687	167.94	13.33					
—— Barbadoes, Monmouthshire . .	2.348	146.75	15.26					
—— Binnie, Linlithgowshire . .	2.246	140.06	15.99					
—— Bolton Quarry, Yorkshire . .	2.028	126.78	17.66					

We have a great variety of sandstones composed of quartzose grains principally, united together in most instances by an argillo-silicious cement, with various proportions of mica; the less we find of the latter ingredient, the sounder the stone; we may, perhaps, venture on dividing the sandstones into 4 divisions, remembering however, that there are a multitude of varieties of each division;—I, A sandstone of a grey, or bluish grey, fine, compact, very hard, and heavy: this stone is one of the best, as the Craig Leith, and Abercarne, Elland Edge, Kentish rag;—II. A stone of a coarse grained nature, as much so in some instances as the coarsest granite, the grains of which are united by a ferruginous cement; this second division is also composed of stone, hard and heavy, and is often the terror of masons from the quantity of steel "licked off" from their tools: in mouldings, it disintegrates rapidly from frost and wet, but for strength it is one of the best building materials, where however, fine moulding is not required, as it pocks very much under the tools; it is commonly called by the workmen "bastard granite;" such is the "Bramley Fall," and "Heddon;"—

NAME OF MATERIAL.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Pressure.	Constant of Elasticity.	Const. of Transv. Strength	REMARKS.
								III. And next in value as a constructive material, we have a stone of a greenish and greenish brown tint, pretty hard, moderately heavy, but by no means equal to the former divisions, the disintegration being here much more rapid than in the former divisions it also generally contains much more mica;—IV. Division; this latter division consists of a stone of red, purple, yellowish red, and bright brown colours, and this last is the worst of the sandstones; (it will be understood that these remarks are general and not special). In the first two divisions the stones may be had of any practicable size, of 4 and 5 feet depths in the III and IV divisions, the beds are generally much thinner the III division yields the Yorkshire flags, and stones which may be very advantageously used in the construction of small arches. Abercarne 4½*d.* per foot cube at quarry 1*s* 5*d.* in London; Barbadoes, 10*d.* at quarry Bolton Quarry 10*d.*, and 1*s.* at quarry; in London, 1*s.* 9*d.* and 2*s.* 1*d.*
—— Bramley Fall, Yorkshire . .	2.275	142.20	15.75	. .	. .	. .	. .	Blocks up to 18 tons; much used in hydraulic works.
—— Calverley, Tunbridge Wells, Kent	1.388	118.06	19.82	. .	. .	. .	. .	Brownish; beds 3¼ ft. thick; price at quarry 4*d.* to 6*s.*; 1*s.* 2*d.* and 1*s.* 4*d.* in London: much used in Kent.

—— Craig-Leith, near Edinburgh . .	2.318	145.90	15.35	. .	4000	. .	. .
—— Crawbank, Linlithgowshire .	2.063	129.00	17.44	. .	. .	. .	. .
—— Duffield Bank, Derbyshire . .	2.125	132.86	16.90	. .	. .	. .	. .
—— Duke Quarries, Derbyshire .	2.312	144.50	15.50	. .	. .	. .	. .
——Gatherley Moor, Yorkshire . .	2.172	135.80	16.49	. .	. .	. .	. .
—— Gatton, Surrey	1.646	103.00	21.74	. .	. .	. .	. .
—— Glamis, Forfarshire . . .	2.545	161.10	13.90	. .		. .	. .
—— Heddon, Northumberlandshire .	2.093	130.85	17.11	. .	. .	. .	. .

TABLE OF SPECIFIC GRAVITIES, &c.—*Continued.*

NAME OF MATERIAL.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Cohesion in lbs. per square inch. Pressure.	Constant of Elasticity.	Const. of Transv. Strength	REMARKS.
—— Hollington, Staffordshire .	2.128	133.00	16.84	. .	. .	. .	. .	Light brown grey; moderately fine; 30 ft. and 40 ft. square; and 8 ft. thick; 7*d.* to 1*s.* at quarry; 2*s.* 5*d.* in London; in Staffordshire and Derbyshire.
—— Humbie, Linlithgowshire . .	2.243	140.20	15.97					
—— White Grey .	2.172	135.80	16.49	. .	. . .	. .	. .	Light grey and light brown; 8 ft. thickest bed; fine grained; 1*s.* to 1*s.* 10*d.* at quarry; 2*s.* 6*d.* to 3*s.* 6*d.* in London; Edinburgh and Glasgow.
—— Longannet, Perthshire . .	2.107	131.70	17.00	. .	. .	. .	. .	Light reddish brown; fine grained; 5 ft. for thickest bed; 8*d.* to 2*s.* 6*d.* at quarry; 1*s.* 8*d.* and 3*s.* 6*d.* in London.
—— Munlochy, Ross-shire . . .	2.569	160.56	13.95	. .	. .	. .	. .	Red variegated; fine grained; beds 2½ ft. to 6 ft. thick; 5*d.* at quarry.
—— Park Spring, Yorkshire . .	2.416	151.06	14.82	. .	. .	. .	. .	Light rusty brown; fine grained; 2¼ ft. thickest bed; 7*d.* at quarry; 2*s.* 1½*d.* and 2*s.* 5*d.* in London.
—— Pensher, Durham	2.418	134.30	16.67	. .	. .	. .	. .	Light brown; coarse; thickest bed 20 ft.; 8¾*d.* at quarry; 1*s.* 7*d.* in London; in demand.

—— Pyotdykes, Forfarshire	2.600	162.50	13.78	. .	5000	. .	. .	Dark grey; fine grained; 3 ft. to 4 ft. thickest bed; 10*d.* to 1*s.* 2*d.* at quarry; 2*s.* 1d. to 2*s.* 5*d.* London; Dundee Harbour.
—— Ringoodie, Perthshire	2.560	160.00	14.00	. .	. .	. .	. .	Dark grey; fine grained; any practicable size; 9*d.* to 1*s.* 5*d.* at quarry; many ancient buildings, and in hydraulic works.
—— Scotgate, Yorkshire	2.528	158.00	14.24	. .	. .	. .	. .	Light greenish grey; moderately fine, $3\frac{1}{2}$ ft. thickest bed; 8*d.* at quarry; 1*s.* 2*d* in London.
—— Stancliff, Derbyshire	2.371	148.20	15.11	. .	3500	. .	. .	Light rusty brown; moderately fine: large size blocks; 1*s.* 5*d.* at quarry; 3*s.* 3*d.* in London.
—— Stenton, Durham	2.280	142.50	15.71	. .	. .	. .	. .	Light rusty brown; fine grained; 2 ft. to 8 ft. thick; $5\frac{1}{2}$*d.* at quarry; 1*s.* 5*d.* in London.
—— Whitby Company, Yorkshire	2.028	126.80	17.66	. .	. .	. .	. .	Light brown; moderately fine; large blocks; 10*d.* at quarry; 1*s.* 8*d.* in London; much used in different parts of England; Hungerford Market, London, Cemetery at Highgate.
Shingle	1.424	89.00						
Slate, Welsh	2.880	180.00	12.44					
Do. Westmoreland, from	2.771	178.00	12.94					
to	2.795	174.50						
Do. Anglesea	2.876	179.75						
Do. Cornwall, light blue	2.512	157.00						

Table of Sets and Deflections on Cast Iron Girders.

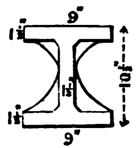
Sections of Girders.	No.	Bearing in feet and inches.	Breaking Weight in tons, according to Formula of E. Hodgkinson, Esq	Permanent Deflections when tested in inches.	Remarks.
Section 1. 					Deflections in inches under a train of 6 cargs. at 30 m. [per hour.
	1	6,10	43.2	- -	0.02
	2	- -	- -	- -	0.03
	3	- -	- -	- -	0.03
	4	- -	- -	- -	0.02
					Do. do.
	5	8,0	34.8	- -	0.04
	6	- -	- -	- -	0.05
	7	- -	- -	- -	0.05
	8	- -	- -	- -	0.04
	9	- -	- -	- -	0.04
					Do., 4 luggage waggons.
	10	- -	- -	- -	0.06
	11	- -	- -	- -	0.09
					Do., 4 carriages.
	12	8,9	33.7	- -	0.06
	13	- -	- -	- -	0.12

Table of Specific Gravities, &c.—*Continued.*

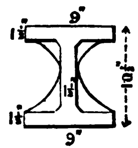
Name of Material.	Specific Gravity.	Weight per cubic foot.	Cubic feet per ton.	Cohesion in lbs. per square inch. Tension.	Cohesion in lbs. per square inch. Pressure.	Constant of Elasticity.	Const. of Transv. Strength	Remarks.
Steel from . .	7.840	490.00	. .	. .	. .	. .	. .	See Mr. G. Rennie's experiments, page 88.
to . .	7.776	486.00						
Teak . . .	.745	46.56	48.11	. .	1400	309000, or 178	2460	
Tile from . .	1.816	113.50						
to . . .	1.856	116.00						
Tin, cast . .	7.291	455.70	. .	16000	3500			
hammered .	7.299	456.20						
Water, sea . .	1.027	64.18						
rain . .	1.000	65.50	. .	. .	. .	. .	. .	1 cubic foot = 6 gallons, 1 pint.
Zinc . . .	7.184	449.00						

CHAPTER VII.

TABLE

OF SETS AND DEFLECTIONS ON CAST IRON GIRDERS.

TABLE OF SETS AND DEFLECTIONS ON CAST IRON GIRDERS.

SECTIONS OF GIRDERS.	No.	Bearing in feet and inches.	Breaking Weight in tons, according to Formula of E. Hodgkinson, Esq	Permanent Deflections when tested in inches.	REMARKS.
SECTION 1. 					Deflections in inches under a train of 6 cargs. at 30 m. [per hour.
	1	6,10	43.2	- -	0.02
	2	- -	- -	- -	0.03
	3	- -	- -	- -	0.03
	4	- -	- -	- -	0.02
					Do. do.
	5	8,0	34.8	- -	0.04
	6	- -	- -	- -	0.05
	7	- -	- -	- -	0.05
	8	- -	- -	- -	0.04
	9	- -	- -	- -	0.04
					Do., 4 luggage waggons.
	10	- -	- -	- -	0.06
	11	- -	- -	- -	0.09
					Do., 4 carriages.
	12	8,9	33.7	- -	0.06
	13	- -	- -	- -	0.12

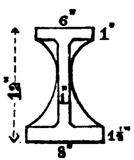
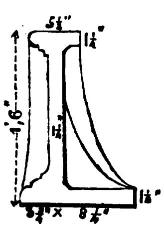
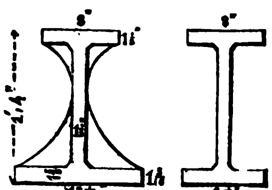
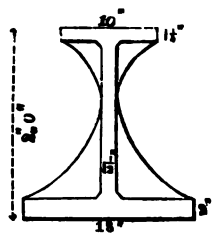
				10 tons in centre.	
	14	10,0	29.5	0.12	
	15	- -	- -	0.18	
	16	- -	- -	0.15	
	17	- -	- -	0.15	
	18	- -	- -	0.12	
	19	- -	- -	0.16	
SECTION 2. 					Deflections under train of 4 cargs., at 30 m. per hour.
	20	8,0	37.5	- -	0.05
	21	- -	- -	- -	0.06
	22	- -	- -	- -	0.05
	23	- -	- -	- -	0.03
SECTION 3. 	24	15	45	20 tons in centre.	Cast flat.
	25	- -	- -	0.06	
				0.12	

TABLE OF SETS AND DEFLECTIONS ON CAST IRON GIRDERS. *Continued*

SECTIONS OF GIRDERS.	No.	Bearing in feet and inches.	Breaking Weight in tons, according to Formula of E. Hodgkinson, Esq	Permanent deflections when tested in inches.	REMARKS
SECTION 4.  Centre. End.					Luggage train, 16 miles per hour.
	26	. .	. .	. .	0.12
	27	. .	. .	. .	0.12
		19	34.5	. .	5 carriages, 33 miles per hour
	28	. .	. .	. .	0.09
	29	. .	. .	. .	0.07
					4 do., 36 miles per hour
	30	. .	. .	. .	0.09
	31	. .	. .	. .	0.12
	32	. .	. .	. .	0.12
	33	. .	. .	. .	0.09
					Do., 40 miles per hour.
	34	. .	. .	. .	0.18
	35	. .	. .	. .	0.18
	36	. .	. .	. .	0.15
	37	. .	. .	. .	0.18
	38	. .	. .	. .	0.15
	39	. .	. .	. .	0.15
	40	. .	. .	. .	0.22
	41	19.9	33.2	. .	0.13

				4 carriages, 25 miles per hour.
42	- -	- -	- -	0.12
43	- -	- -	- -	0.12
44	- -	- -	- -	0.15
45	- -	- -	- -	0.12
				5 do., 30 miles per hour.
46	- -	- -	- -	0.14
47	- -	- -	- -	0.14
48	- -	- -	- -	0.21
49	- -	- -	- -	0.15
50	- -	- -	- -	0.15
51	- -	- -	- -	0.12
52	- -	- -	- -	0.12
53	- -	- -	- -	0.21
	28,0	64.3	30 tons in centre.	
54	- -	- -	0.68	
55	- -	- -	0.56	
56	- -	- -	0.56	
57	- -	- -	0.53	
58	- -	- -	0.55	
59	- -	- -	0.52	Cast on edge.
60	- -	- -	0.50	
61	- -	- -	0.56	
62	- -	- -	0.43	
63	- -	- -	0.56	
64	- -	- -	0.48	
65	- -	- -	0.50	
66	- -	- -	0.62	
67	- -	- -	0.50	

Table of Sets and Deflections on Cast Iron Girders.—*Continued.*

Sections of Girders.	No.	Bearing in feet and inches.	Breaking Weight in tons, according to Formula of E. Hodgkinson, Esq.	Permanent Deflections when tested in inches.	Remarks.
		28.6	63.1	30 tons in centre.	
	68	- -	- -	0.59	
	69	- -	- -	0.56	Cast on edge.
	70	- -	- -	0.59	
	71	- -	- -	0.68	
Section 5. 		30	60	30 tons in centre.	
	72	- -	- -	0.45	
	73	- -	- -	0.47	
	74	- -	- -	0.47	
	75	- -	- -	0.54	
	76	- -	- -	0.56	
	77	- -	- -	0.55	
	78	- -	- -	0.50	Cast on edge.
	79	- -	- -	0.54	
	80	- -	- -	0.43	
	81	- -	- -	0.56	
	82	- -	- -	0.50	
	83	- -	- -	0.50	
	84	- -	- -	0.56	
	85	- -	- -	0.50	
	86	- -	- -	0.62	

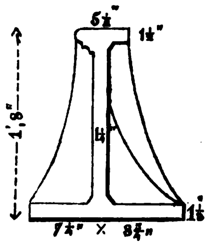
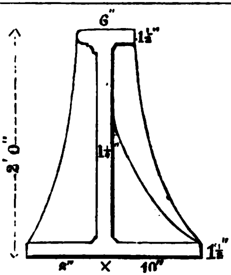
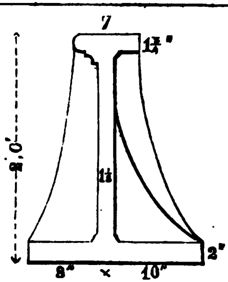
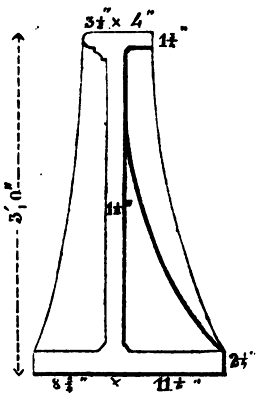
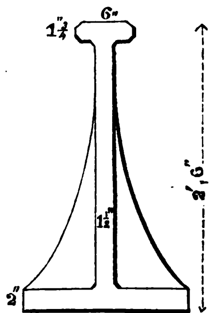
Section 6. 		20	50	20 tons in centre.	
	87	- -	- -	0 18	Cast flat.
	88	- -	- -	0.18	
Section 7. 		20	67.5	20 tons in centre.	
	89	- -	- -	0.12	Cast flat.
	90	- -	- -	0.21	
Section 8. 		30	60.	30 tons in centre.	
	91	- -	- -	0.94	Cast flat.
	92	- -	- -	0.94	
	93	- -	- -	0.75	
	94	- -	- -	1.00	

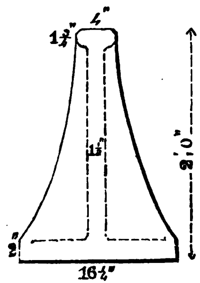
Table of Sets and Deflections on Cast Iron Girders.—*Continued.*

Sections of Girders.	No.	Bearing in feet and inches.	Breaking Weight in tons, according to Formula of E. Hodgkinson, Esq	Permanent Deflections when tested in inches.	Remarks.
Section 9. 		40	84.1	40 tons in centre.	
	95	- -	- -	0.87	
	96	- -	- -	0.75	Cast flat.
	97	- -	- -	0.85	
	98	- -	- -	0.87	
	99	- -	- -	0.63	Another foundry.



Section 10.

Centre.

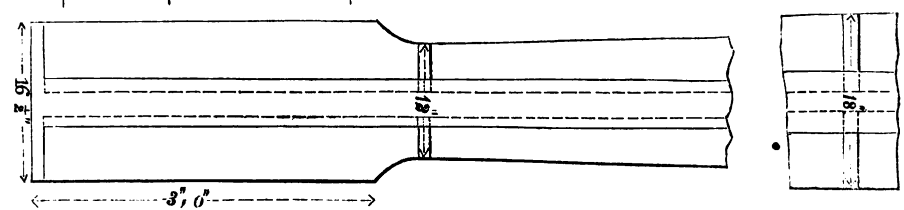


Section 10*a*.

End.

(K)

			20 tons in centre.
100	- -	- -	0.68
101	36	62.5	0.63
			30 tons in centre.
102	42	53.5	1.43
103	- -	- -	1.75
			20 tons in centre.
104	- -	- -	0.94
105	- -	- -	0.87
106	- -	- -	1.12
107	- -	- -	1.13



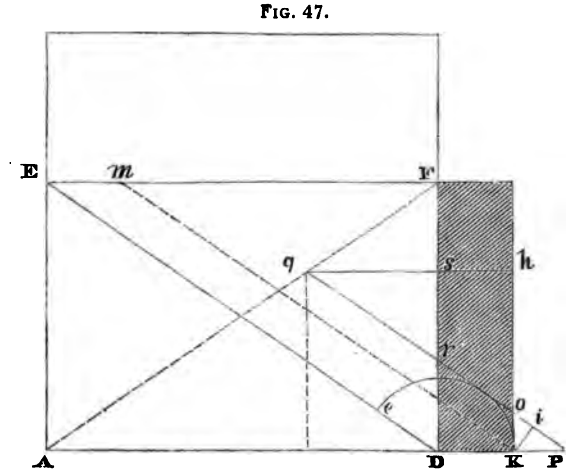
From end to end 48 feet.

CHAPTER IX.

Retaining Walls.

53. AMONGST all our authors, French or English, we have found Rondelet the most practical and generally intelligible on this matter, and we shall consequently follow him on the subject, certainly of great importance in engineering works, and we shall conclude by some few practical remarks and rules, which will be found useful. Our author was first desirous of ascertaining the angle of repose of various earths, and made the following experiments for the purpose, by means of a box, Fig. 47, $16\frac{1}{2}''$

FIG. 47.



$\times\ 12'' \times 17\frac{1}{2}''$, internal measurements; and he found that the angle of repose of very fine sand was $34^\circ\ 30''$,* as in triangle

* The experiments of George Rennie, Esq., give 32° and 33°.

E A D, A E being $11\frac{1}{3}''$; the triangle E D F would therefore represent the sand whose effort tends to overturn a stone flag by which the front of the box was closed up in front as at D F. To ascertain the value of this effort, and the thickness which the flag .iould have to resist it, we must obtain the value of the triangle E D F in dimensions and weight; area of triangle = $93\frac{1}{2}$, and as the specific gravity of the sand is only $\frac{13}{15}$ of that of the stone, it will be reduced to $73\frac{1}{2} \times \frac{13}{15} = 81$. Supposing this mass to slide on the inclined plane E D, the effort will be to the weight as A E : E D : : $\frac{1}{3}$: 20, from which we obtain $81 \times \frac{11\frac{1}{3}}{20} = 45.9$; this effort must be considered as an oblique power $q\,r$, passing through the centre of gravity of the mass, and acting at the extremity of a lever $i\,k$, and the length of this lever depends on the thickness of the flag which is not yet ascertained; but in the similar triangles $q\,s\,r$, $q\,h\,o$, $k\,i\,o$, $q\,s : s\,r :: q\,h : h\,o$; and K$o = h\,k - h\,o$, we shall have $q\,r : q\,s :: h\,k - h\,o : \frac{h\,k - h\,o \times q\,s}{q\,r}$. The three sides of the $q\,s\,r$ are known from the position of the centre of gravity q, each side of lesser triangle $q\,s\,r$, being equal to the third of the corresponding side of the greater triangle E F D, $s\,r$ being equal to a third of F D, $q\,s$ = one third of E F, and $q\,r$ = one third of E D; and calling

$$
\begin{aligned}
q\,r &= a,\\
q\,s &= b,\\
r\,s &= c,\\
s\,h \text{ unknown} &= x,\\
h\,k &= f,\\
\text{the thrust } 45\ q &= p,\\
\text{the height of D F} &= d,
\end{aligned}
$$

we shall have $b : c : b + x : \frac{b\,c + c\,x}{b} = h\,o$, and $h\,k - h\,o$, will be $f - \frac{b\,c - c\,x}{b}$; and we shall find $i\,k$ by the proportion $a : b :: f - \frac{b\,c - c\,x}{b} : \frac{b\,f - b\,c - c\,x}{a} = i\,k$, which will give the result of the thrust p, multiplied by the length of lever $\frac{b\,f - b\,c - c\,x}{a} = \frac{p\,b\,f - p\,b\,c - p\,c\,x}{a} = \frac{d\,x\,x}{2} =$ the resistance of the flag. From this equation we obtain $\frac{2\,p\,b\,f - 2\,p\,b\,c}{a\,d} = x\,x + \frac{2\,p\,c\,x}{a\,d}$; and to

facilitate the solution, making $\frac{2pbf - 2pbc}{ad} = 2\,m$, and $\frac{2pcx}{ad} = 2\,n$, we shall have $xx + 2\,nx = 2\,m$; adding to each member the square of n, to make the first term a perfect square, from which we can extract the root, we shall have $xx + 2\,nx + nn = 2\,m + nn$, and $x + n = \sqrt{2\,m + nn}$; and at last $x = \sqrt{2\,m + nn} - n$, which is the general formula to resolve all such problems. Referring back to the values of the known quantities expressed by letters, we shall have,

$$a = 6\tfrac{2}{3}$$
$$b = 5\tfrac{1}{2}$$
$$c = 3\tfrac{3}{4}$$
$$f = 7\tfrac{5}{9}$$
$$p = 45\tfrac{9}{10}$$
$$d = 11\tfrac{1}{3};$$

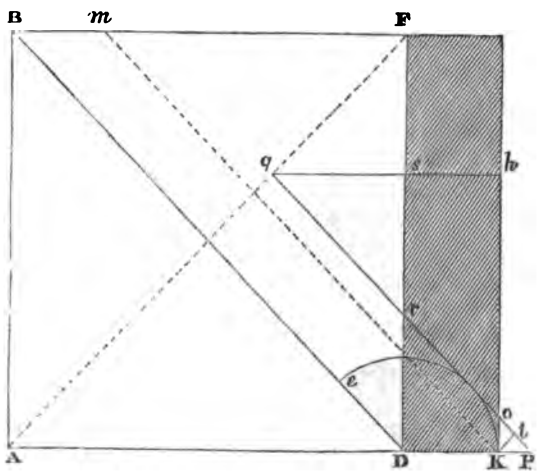
$m = pb \times \frac{f - c}{ad}$ will become $m = 45.9 \times 5\tfrac{1}{2} \times \frac{7\frac{5}{9} - 3\frac{3}{4}}{6\frac{2}{3} + 11\frac{1}{3}}$, from whence we obtain

$$m = 12.70,$$
$$2\,m = 25.4,$$

and $n = \frac{pc}{ad}$ will become $\frac{45.9 \times 3.75}{75.55} = 2.28$ and $nn = 5.20$. This result agrees as nearly as can be expected with the experiment, since it was found that $3\tfrac{1}{4}$ were the required dimensions for the flag, to resist the thrust of the sand, which overturned a flag of 3 inches thickness. Another application of this theory is the following, in which from experiment on common earth well dried and pulverised, the angle of repose was 46°, 50′; the superficies of the thrusting earth is $144\tfrac{7}{9}$ inches, but as the weight of an equal volume of this earth is only equal to $\tfrac{3}{4}$ of that of the resisting flag, it is reduced to 108 inches; the thrust of this mass acting on the inclined plane $q\,r$, is to its weight as A B is to B D, or as $17\tfrac{1}{2}$ to 24, by which it is reduced to $78\tfrac{3}{4}$. As in the former case the thrust will proceed from a triangle B D F, Fig. 48, similar to the lesser triangle $q\,r\,s$, having one of its angles at the centre of gravity of B D F; in these the sides are also proportional, and the sides of the lesser triangle will be equal to one third of the corresponding sides of the greater triangle. By calculations similar to those in the former case, we shall have

$$q\,r = a = 8,$$
$$q\,s = b = 5\tfrac{1}{2},$$
$$s\,r = c = 5\tfrac{5}{8},$$
$$s\,\mathrm{D} = f = 10\tfrac{5}{8},$$
$$\text{the thrust} = p = 78\tfrac{3}{4},$$
$$\text{the height of the flag} = d = 17\tfrac{1}{2};$$

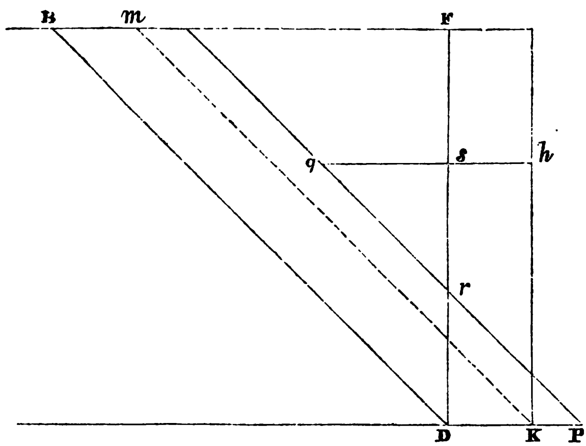
FIG. 48.



from whence, m in the formula $p\,b \times \frac{f-c}{a\,d}$, will be $m = 78.55 \times 5.5 \times \frac{10.66 - 5.83}{8 \times 17\frac{1}{2}}$, or $m = 18.04$ and $2\,m = 36.08$; and $n = \frac{p\,c}{a\,d}$ will become $n = \frac{78.55 \times 5.83}{8 \times 17\frac{1}{2}}$, or $n = 3.2$, and $n\,n = 10.24$; substituting these values in the formula $x = \sqrt{2\,m + n\,n} - n$, we have $x = \sqrt{36.08 + 10.24} - 3.2$, or $x = 6.8 - 3.2$, or $x = 3\frac{6}{10}$ inches for the thickness of the stone flag; by the experiment the thickness required was only 3 inches, and this must be attributed to cohesion. A further application is on earth at an angle of repose 45°, Fig. 48; $q\,s = s\,r = b = c = \frac{d}{3}$, and $f = \frac{2\,d}{3}$, which instead of $m = p\,b \times \frac{f-c}{a\,d}$, gives $m = \frac{p\,d}{3} \times \frac{2\,d - d}{3\,a\,d} = \frac{2\,p\,d\,d - p\,d\,d}{3\,a\,d}$, or $\frac{p\,d}{q\,a}$, and instead of $n = \frac{p\,c}{a\,d}$, we have $\frac{p\,d}{3\,a\,d}$, or $\frac{3\,a}{p}$. The superficies of the isosceles right-angled triangle B D F, from whence the thrust proceeds will be $16\frac{1}{2} \times 8\frac{1}{4} = 136$, of which the $\frac{3}{4}$ are equal to 102, and this weight will be

to the thrust as 10 to 7, from whence we obtain 71.4 for the value of p; a will be equal to $7\frac{7}{9}$.

FIG. 49.



From these values we have,

$$m = \frac{71.4 \times 16.5}{7\frac{7}{9} \times 9} = \frac{1178.1}{70} = 16.83;$$

$$n = \frac{71.4}{7\frac{7}{9} \times 3} = 3.06, \text{ and } n\,n = 9.36;$$

these values being substituted in the formula $x = \sqrt{2\,m + n\,n} - n$, give $x = \sqrt{36.66 + 9.36} - 3.06 = 6.57 - 3.06$, or $x = 3\,\frac{51}{100}$ in. Adopting generally 45° for the angle of repose of earths, we may obtain a formula, which will only require, as a known quantity, the height of the earth to be supported; thus referring back to the equation $x = \sqrt{2\,m + n\,n} - n$, in which it has has been shown that $m = \frac{p\,d}{q\,a}$ and $n = \frac{p}{3\,a}$; in order to reduce these expressions to others, containing only the height expressed by d, it will be observed, that the superficies of the earth, B F D, from whence proceeds the thrust, will be $d \times \frac{d}{2} = \frac{d\,d}{2}$; and taking the $\frac{3}{4}$ of this as the corresponding ratio to the specific gravity of masonry, we shall have $\frac{d\,d}{2} \times \frac{3}{4} = 3\,\frac{d\,d}{8}$. The thrust of this triangle on the inclined plane of 45°, will be to its weight, as the height A B is to the length B D; as the side of the square is to the diagonal as 70 to 99 nearly, we shall have for the thrust $\frac{3\,d\,d}{8} \times \frac{70}{99} = p$, and $p\,d = \frac{3\,d\,d\,d}{8} \times \frac{70}{29}$. This

quantity being divided by 9 a, it will be observed that a is equal to $\frac{1}{3}$ of the diagonal B D. Therefore we shall have,

$$70 : 99 :: d : \frac{99 \times d}{70} = 3\,a,$$

and,

$$9\,a = \frac{3\,d \times 99}{70},$$

which gives,

$$m = \frac{3\,ddd \times 70 \times 70}{8 \times 3\,d \times 99 \times 99} = \frac{3\,ddd \times 4900}{24\,d \times 9880},$$

or

$$\frac{dd}{8} \times \frac{1}{2} = \frac{dd}{16} = m, \text{ and } 2\,m = \frac{dd}{8};$$

$$n = \frac{p}{3\,a} \text{ will become } \frac{3\,dd \times 70 \times 70}{8\,d \times 99 \times 99},$$

or

$$\frac{3\,d}{8} \times \frac{1}{2} = \frac{3\,d}{16},$$

which gives

$$x = \sqrt{\frac{dd}{8} + \frac{3\,d}{16} \times \frac{3\,d}{16}} - \frac{3\,d}{16};$$

applying this formula to the preceding example, we shall have,

$$x = \sqrt{\frac{16\frac{1}{2} \times 16\frac{1}{2}}{8} + \frac{16\frac{1}{2} \times 3}{16} \times \frac{16\frac{1}{2} \times 3}{16}} - \frac{16\frac{1}{2} \times 3}{16},$$

or,

$$x = 3.51$$

as before.

54. If it were required to find the dimensions of a battering wall, instead of those of a plumb wall, and the resisting strength of which should be equal to that of the plumb wall, we should have to consider the sectional area of the battering wall, as consisting of a rectangle D F H I, and of a triangle of H I K; as any ratio of slope may be assumed for the batter, the length of I K will be a known quantity, and we shall only have to find D I for the rectangle; make, Fig. 50.

the height of the wall $= d$,
base of slope $= a$,
base of rectangle $= x$,

as the direction of the centre of gravity G, of the rectangle falls at L, in the centre of D I, the length of its lever with regard to the fulcrum K will be $a + \frac{x}{2}$, and the centre of gravity g, of the

triangle falling M, and at $\frac{2}{3}$ of I K from K, we shall have for the resistance of the wall,

$$d x \times a + \frac{x}{2} + \frac{d a}{2} \times \frac{2 a}{3},$$

equal to the resistance of the plumb wall, which we will term **R**, and we get the equation,

$$a d x + \frac{d x x}{2} + \frac{2 a^2 d}{6} = \mathrm{R};$$

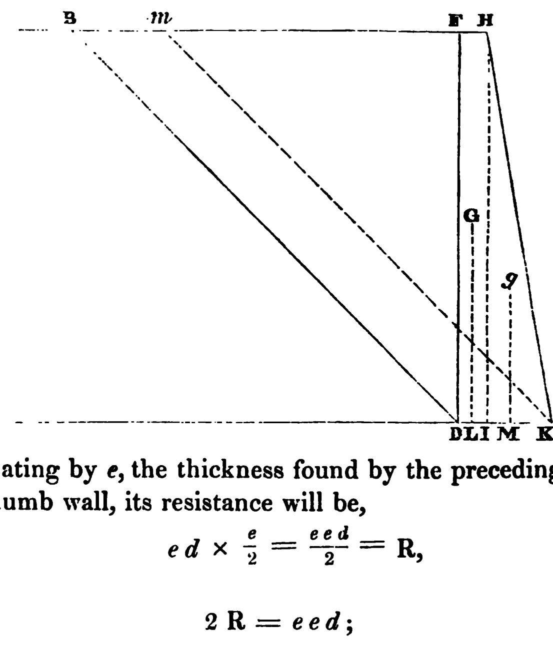
dividing by d and multiplying by 2, we obtain,

$$x x + 2 a x = \frac{2 \mathrm{R}}{d} - \frac{2 a^2}{3};$$

and adding to each term the square of a, we get,

$$x + a = \sqrt{\frac{2 \mathrm{R}}{d} = \frac{2 a^2}{3} + a a}.$$

Fig. 50.



Designating by e, the thickness found by the preceding formula for a plumb wall, its resistance will be,

$$e d \times \frac{e}{2} = \frac{e e d}{2} = \mathrm{R},$$

and

$$2 \mathrm{R} = e e d;$$

and,

$$\frac{2 \mathrm{R}}{d} = e e$$

which introduced into the preceding formula instead of $\frac{2 \mathrm{R}}{d}$ will give,

$$x + a = \sqrt{e e - \frac{2 a^2}{3} \quad a a},$$

and,

$$x = \sqrt{ee - \frac{2\ a^2}{3} + a\ a} - a.$$

The thickness e having been found to be 3.51, the square of it will give 12.3201 ; and assuming for the base of the batter $\frac{1}{6}$ of the height $= \frac{16.5}{6} = 2.75$, of which the square $= 7.5625$; and by a substitution of values, we obtain

$$x = \sqrt{12.32 - \frac{7.5625 \times 2}{3} + 7.5625} - 2.75,$$

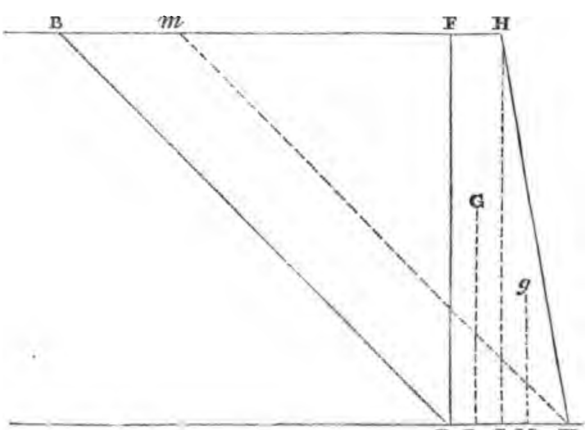
or

$$x = 1.1.$$

Hence we see, that by giving a batter equal to $\frac{1}{6}$ of the height, and 1′.1 for the thickness of the wall at top, the superficies will be 40′$\frac{5}{6}$, and the resistance offered will be equal to that of a rectangular plumb wall, of a uniform thickness of 3′ $\frac{51}{100}$.

55. To find the thickness of the rectangular part D H, of a battering wall, with a sectional area equal to that mentioned above, of 16½ feet high, and 3$\frac{51}{110}$ feet thick, and equal to a sectional area of 57$\frac{183}{200}$ feet, we must, having assumed the batter, deduct the area of the triangle from the given area, and divide the remainder by the height. Thus, for a wall 16½ feet, Fig. 51, and

Fig. 51.

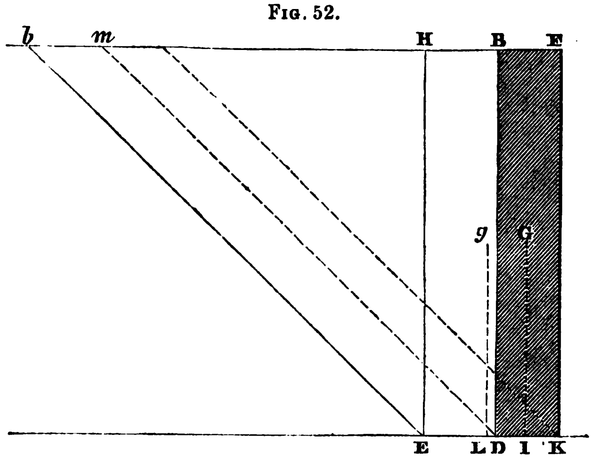


$\frac{1}{6}$ of this height for batter; the sectional area of the triangle is 22$\frac{11}{16}$ feet, and this deducted from 57$\frac{183}{200}$, leaves 35$\frac{91}{400}$, which divided by 16½, gives 2 $\frac{27}{100}$ feet for the thickness of the wall at top, instead of 1.1 foot in Fig. 50; the increase of strength

obtained by this increase of thickness will be measured by the sectional area of the rectangle F H D I $\times$ the length of lever K L + the sectional area of the triangle H I K $\times$ $\frac{2\,\mathrm{IK}}{3}$. And the strength of the plumb wall of equal area will be equal to the sectional area of the rectangle F D H K $\times$ $\frac{\mathrm{DK}}{2}$.

56. Counterforts add considerably to the strength of a wall, but the foregoing remarks with regard to the batter or slope of walls, will show how much greater the additional strength would be, if instead of counterforts constructed at the back of a retaining wall, we were to use buttresses applied exteriorly; we may proceed in the following manner to ascertain the strength of counterforts and of buttresses. In Fig. 52, let B D F, be the section of a retaining wall 16½ feet high, 2½ feet thick, to which it is required to add counterforts, also 2½ feet high, and of a height equal to that of the wall, in order to supply by the addition to defect of thickness, which should be $3\frac{15}{100}$ feet, ac-

Fig. 52.



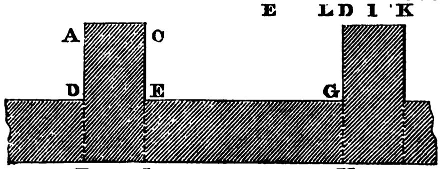


Fig. 52*a*.

cording to the preceding calculations; and let the distance between the counterforts be equal to half the height of the wall, or 8¼ feet. To ascertain the strength of such a wall with the

counterforts, we must calculate on a portion between the centres of these, or, which is the same thing on an intermediate part, and on a counterfort with the part of the wall attached to it, as in E S G H, and A D B S E C, Fig. 52, 52*a*; and let

$$\text{the height} = d,$$

$$\text{the length of wall between counterforts} = \frac{d}{2},$$

$$\text{thickness of wall} = e,$$

$$\text{thickness of counterforts} = e,$$

$$\text{and the length of counterforts} = x,$$

$$\text{the length of lever, I K} = \frac{e}{2}$$

$$\text{ditto,} \quad \text{L K} = \frac{x+e}{2};$$

the cube of the wall between the counterforts will be,

$$d \times \frac{d}{2} \times e = \frac{d^2 e}{2};$$

and the length of leverage being $\frac{e}{2}$, the resistance will be

$$\frac{d^2 e}{2} \times \frac{e}{2} = \frac{d^2 e^2}{4};$$

the cube of the counterfort with the adjoining portion of the wall will be,

$$e + x \times d \times e,$$

or

$$d e^2 + d e x;$$

the length of leverage being $\frac{e+x}{2}$, its resistance will be expressed by,

$$\frac{d e^3 + 2 d e^2 x + d e x x}{2}$$

and designating by R, thrust which the wall and the counterfort have to sustain, we have the equation,

$$\frac{d^2 e x}{2} + \frac{d^2 e^2}{4} + \frac{d e^3 + 2 d e^2 x + d e x x}{2} = \text{R},$$

or

$$\frac{d e x^2 + 2 d e^2 x}{2} = \text{R} - \frac{d e^3}{2} - \frac{d^2 e^2}{4},$$

or multiplying by 2, and dividing by $d e$,

$$x x + 2 e x = \frac{2 \text{R}}{d e} - e^2 - \frac{d e}{2},$$ or adding to each member the square of e, in order to extract the root of the first,

$$x^2 + 2 e x + e e = \frac{2 \text{R}}{d e} - \frac{d e}{2},$$

or,

$$x + e = \sqrt{\frac{2\,R}{de} - \frac{d\,e}{2}},$$

or,

$$x = \sqrt{\frac{2\,R}{d\,e} - \frac{d\,e}{2}} - e.$$

Since this wall with the counterforts has to sustain a thrust equal to that resisted by the plumb wall, of which we have ascertained the required thickness to be $3\frac{51}{100}$, we may take the resistance of that wall as the value of R; to find it we must calculate on the length of wall between the counterforts, which is $8\frac{1}{4}$ feet, plus $2\frac{1}{2}$ feet for the thickness of the counterforts, or 10.75 feet, and cubing, we have,

$$10.75 \times 16.5 \times 3.51 = 622.58625,$$

and for the strength,

$$622.58625 \times 1.755 = 1092.64 = R;$$

substituting this and the other known values in the last equation, we find

$$x = \sqrt{\frac{2185.28}{41.25} - \frac{41.25}{2}} - 2.5,$$

or

$$x = 3.188,$$

for the length of the counterforts.

57. If we substitute buttresses on the face of the wall, for counterforts at the back, Fig. 53, and 53*a*, the leverage, I K, of the part of the wall between the buttresses, will be equal to x, plus half the thickness of the wall, or

$$x + \frac{e}{2},$$

the cube of which, being expressed as in the preceding example by,

$$\frac{d\,e}{2},$$

the resistance will be,

$$\frac{d^2\,e\,x}{2} + \frac{d^2\,e^2}{4}.$$

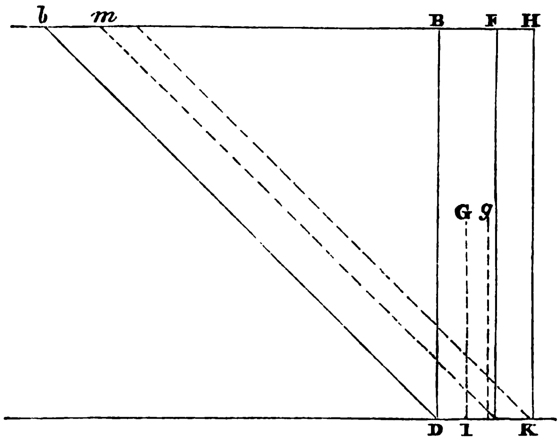
The cube of the buttress and portion of attached wall will be as before

$$de^2 + d\,e\,x,$$

and its resistance,

$$\frac{d\,e^3 + 2\,d\,e^2\,x + d\,e\,x\,x}{2}$$

FIG. 53.



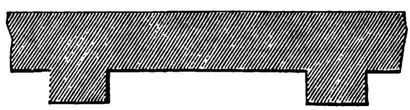


FIG. 53*a*.

These two resistances give the equation,

$$\frac{d^2 e x}{2} + \frac{d^2 e^2}{4} + \frac{d e^3 + 2 d e^2 x + d e x x}{2} = \mathrm{R};$$

or

$$\frac{d e x x + d^2 e x + 2 d e^2 x}{2} = \mathrm{R} - \frac{d e^3}{2} - \frac{d^2 e^2}{4};$$

multiplying by 2 and dividing by $d\,e$, we have

$$x x + d x + 2 e x = \frac{2\,\mathrm{R}}{d e} - e^2 - \frac{d e}{e},$$

and making the quantity $d + 2e$ by which x is multiplied $=$ $2\,n$, we obtain

$$x x + 2 n x = \frac{2\,\mathrm{R}}{d e} - e^2 - \frac{d e}{2};$$

adding to each number $n\,n$, in order to extract the root from the first, we get

$$x x + 2 n x + n n = \frac{2\,\mathrm{R}}{d e} - e^2 - \frac{d e}{2} + n n;$$

and extracting the root,

$$x + n = \sqrt{\frac{2\,\mathrm{R}}{d e} - e^2 - \frac{d e}{2} + n n};$$

or,

$$x = \sqrt{\frac{2\,\mathrm{R}}{d e} - e^2 - \frac{d e}{2} + n n} - n,$$

and substituting the values in this equation, we obtain

$$x = \sqrt{\frac{2185.28}{16.5 \times 2.5} - 2.5 \times 2.5 - \frac{16.5 \times 2.5}{2} + 10.75 \times 10.75} - 10.75,$$

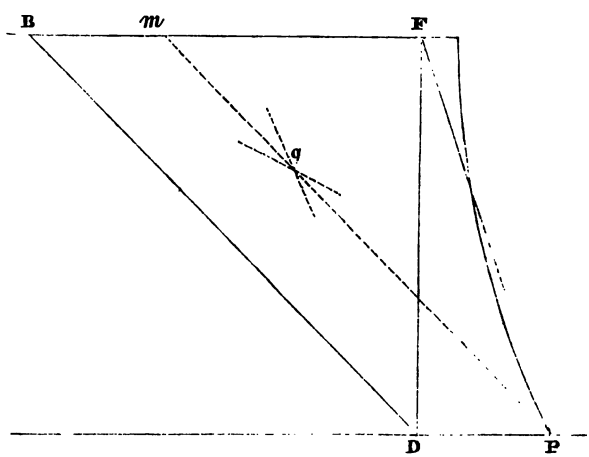
or,

$$x = 1.53,$$

for the length of the buttresses, instead of 3.188 for the length of the counterforts.

58. Desirous to ascertain by experiment, and independently of theory, and precedents in similar constructions, the most suitable forms for retaining walls, Rondelet made a great number of experiments, the result of which he considers to be, that if from the centre of gravity q, of a triangular mass of earth, q P, Fig. 54, be drawn parallel to the line of the slope B D

FIG 54.

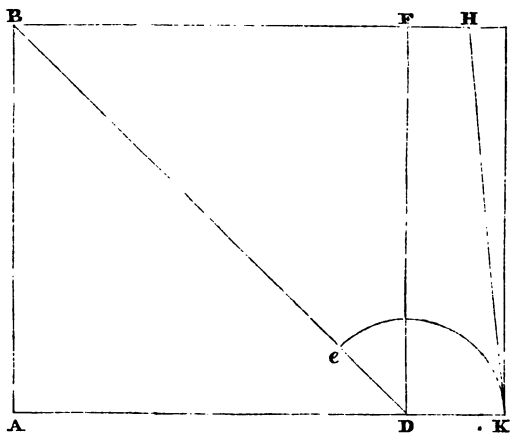


and P F joined, the triangle F D P will be the strongest form for a retaining wall. He adds that a revetement in wood similar in sectional area to this triangle, was sufficient to resist the thrust of the sliding sand, although the specific gravity of the wood was hardly half that of the sand. This datum affords us a very simple means to obtain the requisite thickness of a wall of this kind, and we may easily make use of it for the curvilinear batter which has been so much in use, merely making the top of the wall of a certain thickness, say 1 foot 6 inches, as in Fig. 54, the centre of the curve being on B F produced.

59. We must not overlook in this place that in all the preceding cases, the triangular sectional area of earth is very great, natural cohesion being entirely neglected, and the substances experimented on being reduced to powder, when they would assume a far greater slope than usual, in cutting, and where the surface would not be exposed to the injurious atmospherical effects of rain and frost; therefore the rules laid down would be in excess, though not so much so as in supporting made earth, as in an embankment; also in all the above figures the portion E D K M, B D K M, B D P M, &c., do not require support, as each finds its rest at the foot of the wall.

60. To find by geometrical operation the thickness of a plumb retaining wall, Fig. 55; set out A D B, the angle of repose for

FIG. 55.



the earth, and make D F equal to the height of the wall; complete the square B A D F, and with $\frac{1}{6}$ of the diagonal B D, as a radius describe from centre D, the arc *e k*; K D will be the thickness of the wall.

61. To find by similar means the thickness of a wall battering $\frac{1}{6}$ of the height, or 2 inches to 1 foot; perform the same operation, and for the thickness of the wall at top F H, take $\frac{1}{9}$ of the diagonal B D; for a batter of $\frac{1}{8}$ or $1\frac{1}{2}$ inches to 1 foot, take $\frac{1}{8}$ of the diagonal. Instead, however, of $\frac{1}{9}$ of the diagonal for the thickness at the top, we recommend $\frac{1}{15}$, and for the 8th of the

diagonal take $\frac{1}{13}$, and for a battering wall of 1 inch to a foot, take $\frac{1}{11}$ of the diagonal for the thickness at top. These rules are empyrical, but they agree with practice, and are based on secure data; it must not be forgotten in calculating the thicknesses of retaining walls, to take into consideration the difference between the weight of brick, stone, granite, &c.; we may also consider a buttress 1 foot long in the face of the wall, as affording as much strength as a counterfort 3 feet long at the back, and without losing strength where practically required, we may batter the buttress up to nothing, or nearly so, at top; for dry rubble walls we must take $\frac{2}{3}$ of the height, and never less than $\frac{1}{2}$; these walls are seldom of any height, but they effect a very perfect drainage, and by giving a considerable batter, say 3 inches to the foot, and employing stone of large scantling, at least as regards length and width, considerable strength may be attained; to resist the thrust of water, one half the height of the water will not be in excess for the mean thickness of the wall.

62. It must, however, be carefully noted, that however carefully the engineer may calculate the necessary strength of retaining walls, with due regard to economy, this care will be entirely lost unless close inspection be kept over the masons. The first essential will be the soundness of the foundation, and this more particularly if possible, for buttresses and counterforts; the mortar should be of the best, and sufficient, especially in rubble backing; every two or three courses, according to thickness, should be well grouted; secure as many bondstones as possible, bond the buttresses and the counterforts carefully into the wall; lay drains, and punn well as the wall rises; where the ground slopes towards the wall, it should be well benched, to secure as much as possible the vertical bearing of the backing earth; and the reader may depend on his obtaining these essentials only in proportion to his inspectors' as well as his own watchfulness and close inspection; and the greater the work, the more likely he is to be deceived by pretensions and promises.

CHAPTER X.

Stone and Brick Bridges and Viaducts.

63. ALTHOUGH stone and brick bridges and viaducts form some of the most important features in the construction of railways, a theory on the equilibrium of arches and resistance of piers would be here out of place; and the student is referred for information on this subject to more important works written by more able pens, as Gauthey, Hutton, Ware, Hann, Moseley, and Rondelet. The practical dissertation of the last has been given in English by Mr. Gwilt, in his Encyclopædia of Architecture; all that will be given in these pages consists of a few tables of data, and some memoranda to refresh or assist the memory of the practical man.

TELFORD'S TABLE

Of Proportions for Highland Bridges.

Span.	Versed Sine.	Depth of Arch stone.	Height of Abutments to springing.	Average thickness of Abutment.	Thickness of Spandrils.	Thickness of inverted arches when necessary.
4	1,6	1	2,6	1,6	1,6	0,9
6	2,0	1	2,6	2,0	1,6	1 0
8	3,0	1,2	2,6	2,0	2,0	1,0
10	3,6	1,3	3,0	2,6	2,0	1,0
12	4,0	1,4	3,0	3,0	2,6	1,0
18	6,0	1,6	3,0	4,6	2,9	1,4
24	8,0	1,9	4,0	5,0	2,9	1,4
30	12,0	2,0	4,0	5,6	3,0	1,6
50	15,0	2,6	6,0	6,0	3,6	1,6

TABLE

Of Dimensions for Arches, and Piers for Segmental Arches.

Span of arch in feet.	Depth of arch stone in feet and inches.	Height of piers in feet and inches.	Thickness of piers in feet and inches.	Thickness of piers at springing, with batter, in feet and inches.	Thickness of piers for flat girder bridges in feet and inches.	Thickness of piers for flat girder bridges, with batter, in feet and inches.	Rise of arch in feet and inches.
10	1,2	5	3,0	Or 3 at top, battering ¼ in 12.	2,3	Or 2,3 at top, battering ¼ to 1.	3,0
		10	3,0		2,3		
		15	3,4½		2,7½		
		20	3,9		2,7½		
15	1,6	5	3,0	Do , do.		2,7½ at top, battering ¼ to 1.	4,6
		10	3,4½		2,7½		
		15	3,4½		2,7½		
		20	3,9		3,0		
20	1,6	5	3,0	3 at top, battering ¼ in 12 for 20 feet height; or 3,4½ at top, battering ⅓ in 12 for 40 feet height.		Or 2,7½ at top, battering ¼ to 1.	6,0
		10	3,4½		2,7½		
		15	3,9		2,7½		
		20	3,9		2,7½		
		25	4,1½		3,0		
		30	4,1½		3,0		
		35	4,6		3,4½		
		40	4,6		3,4½		
25	1,6	5	3,9	3,9 at top, battering ⅓ in 12 for 40 feet height.		Or 3,4½ at top, battering ¼ to 1.	7,3
		10	3,9		3,0		
		15	4,1½		3,4½		
		20	4,6		3,9		
		25	4,6		3,9		
		30	4,6		3,9		
		35	4,10½		4,1½		
		40	4,10½		4,1½		
30	1,10½	5	4,1½	4,1 at top, battering ⅓ in 12 for 20 feet height; or 4,6 at top, battering ¼ in 12 for 40 feet height.		Or 4,1½ at top, battering ¼ to 1.	9,0
		10	4,1½		4,1½		
		15	4,6		4,1½		
		20	4,10½		4,1½		
		25	4,10½		4,6		
		30	5,3		4,6		
		35	5,0		4,10½		
		40	6,0		6,0		
35	2,3	10	4,10½	4,10 at top, battering ⅓ in 12 for 20 feet height; or 4,10 at top, battering 1 inch in 3 feet for 40 feet height.	5,3	Or 4,6 at top, battering ¼ inch in 2 feet.	10,6
		15	4,10½		5,3		
		20	5,3		5,7½		
		25	5,3		5,7½		
		30	6,0		6,0		
		35	6,0		6,0		
		40	6,4½		6,4½		

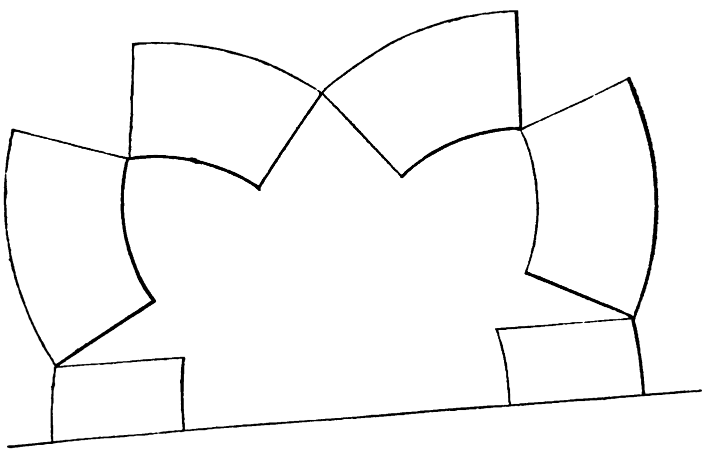
TABLE

Of Dimensions for Arches, and Piers for Segmental Arches.

Span of arch in feet.	Depth of arch stone in feet and inches.	Height of piers in feet.	Thickness of piers in feet and inches.	Thickness of piers at springing, with batter in feet and inches.	Thickness of piers for flat girder bridges in feet and inches.	Thickness of piers for flat girder bridges, with batter in feet and inches.	Rise of arch in feet and inches.
40	2,3	10	5,7½	5,3 at top, battering $\frac{1}{8}$ in 12 for 20 feet height; or 6 feet at top battering, 1 inch in 3 feet for 40 feet height.	4,10½	Or 4,10½ at top, battering ¼ of an inch per foot.	11,3
		15	6,0		5,3		
		20	6,4½		5,3		
		25	6,4½		5,3		
		30	6,9		5,7½		
		35	6,9		6,0		
		40	7,1½		6,0		
45	2,7	10	6,4½	Or 6 at top, battering $\frac{1}{8}$ in 12 for 20 feet height, or 6,4½ at top, battering 1 inch in 3 feet for 40 feet height.	5,7½	Battering ¼ of an inch per foot.	13,0
		15	6,4½				
		20	6,9				
		25	7,1½				
		30	7,1				
		35	7,1				
		40	7,6				
50	3,0	10	7,1	Or 7,1 at top, battering $\frac{1}{8}$ in 12 for 20 feet; or 7,1 at top, battering 1 inch in 3 feet for 40 feet height.	6,9	Do., do.	14,6
		15	7,6				
		20	7,6				
		25	7,10½				
		30	7,10½				
		35	8,3				
		40	8,3				
55	3	10	7,10	Or 7,10 at top, battering height $\frac{1}{8}$ in 12 for 20 feet height; or 7,10 at top, battering ¼ in 12 for 40 feet height.	7,1½	Do., do.	16,0
		15	7,10				
		20	8,3				
		25	8,7				
		30	9,0				
		35	9,4				
		40	9,4				
60	3	10	8,7	Or 8,3 at top, battering $\frac{1}{8}$ in 12 for 20 feet height; or 8,3 at top, battering $\frac{1}{8}$ in 12 for 40 feet height.	7,10½	Do., do.	17,3
		15	8,7				
		20	9,4				
		25	9,4				
		30	9,9				
		35	9,9				
		40	9,9				

64. It has been ascertained by experiments, which have been found to agree with theory, that in a semicircular arch there are four points of rupture, A, B, C, D, Fig. 56; consequently, by

FIG. 56.



using a segmental arch of a certain rise, we get free of two points of rupture, A and D, and this has occasioned the much less frequent use of the semicircular arch of late, except under heavy embankments. In the previous tables for segmental arches, the angles of rupture, A, D, have been considered as at about 30 degrees, though it is a little lower, and the rises or versed sines have been given accordingly.

65. The elliptic form of arch, which is undoubtedly much weaker than the segmental, is still used in railway works, though not so much as formerly; it requires, for equal spans with the segmental arch, greater depth of arch and thicker piers. This form of curve is too often described for arches of 30 ft. and 40 ft., with only three centres, and the resultant curve is not only the weakest of the kind, but scarcely deserves the name of an elliptic curve. Up to 20 ft. span three centres may be used, but above this span we should not use less than five centres for describing the curve. It must not be supposed that the two following diagrams are offered to *teach* the methods of delineating the elliptic curve; they are only given in this place to assist memory on what is easily forgotten.

66. To describe an elliptic from three centres, the span and rise, or the major and semi-minor axes being given:—In Fig. 57, let A B be the span, and O C the rise; complete the parallelogram C O B D, by making B D parallel to O C, and C D parallel to O B; bisect B D at E, and join E C; make O F equal to O C, and join D F, cutting C E at G; bisect C G at K, and draw K L perpendicular to C G, cutting C O produced at L; from L as a centre, with radius L G, describe the curve M G C; through M B draw M B *n*; join *n* L, cutting A B at N, and transfer B N to A N′; N, L, N′, will be the three centres required for describing the curve.

67. Having the span and the rise, to describe a semi-ellipsis with five centres:—In Fig. 58, let A B be the span, and O C the rise; from centre O, with radius O A, or O B, describe the semi-circle A D B, and divide it into six equal parts at 1, 2 D, 3, 4, B, with radius O C; and also from centre O describe the semi-circle E C F, and divide this also into six equal parts, as at *a*, *b*, C, *c*, *d* E; through 1, 2, 3, 4, draw parallels to C O, and through *a*, *b*, *c*, *d*, draw parallels to A B; join the points of intersection *f*, *g*, *h*, *i*, which will be points on the elliptic curve; bisect A *f*, *f g*, *g* C, C *h*, *h i*, *i* B, as at *k*, *l*, *m*, *n*, *o*, *p*; through *m*, and *n*, draw *m* G, and *n* G, perpendicular to *h* C, and *g* C, intersecting C O produced at G, when G will be a centre; through *l* and *o* draw *l* H, *o* H, perpendicular to *f g* and *h i*, and intersecting *m* G and *n* G at H and H′; and H and H′ will be two centres also; through *k* and *p*, perpendicular to A *f* and *i* B, draw *k* K, *p* K′, intersecting A B at K and K′, which will be the two last centres required for the curve of the arch. The greater the number of divisions in the semi-circles, the more numerous the centres, and the nearer will the curve described approach the elliptic. Subjoined are tables of dimensions for elliptical arches.

TABLE

Of Dimensions of Arches and Piers for Elliptical Arches.

Span of arch in feet.	Depth of archstone in feet and inches.	Height of piers in feet.	Thickness of piers in feet and inches.	Thickness of piers at springing, with batter, in feet and inch.	Rise of arch in feet and inches.
10	1,2	5	3,0	3 at top, battering ¼ inch per foot.	3,4
		10	3,4½		
		15	3,9		
		20	4,1½		
15	1,6	5	3,4½	3,4½ at top, battering ¼ inch per foot.	5,0
		10	3,9		
		15	4,1½		
		20	4,1½		
20	1,10½	5	3,9	4,1½ at top, battering ⅛ inch per foot.	6,8
		10	4,1½		
		15	4,1½		
		20	4,6		
		25	4,6		
		30	4,6		
		35	4,10½		
		40	4,10½		
25	1,10½	5	4,1½	4,1½ at top, battering ¼ inch per foot.	8,4
		10			
		15			
		20	4,6		
		25			
		30			
		35			
		40	4,10½		
30	1,10½	5	4,6	4,6 at top, battering ¼ inch per foot for 20 feet height, or 4,10½ at top, battering ¼ inch per foot for 40 feet.	10,0
		10	4,10½		
		15	4,10½		
		20	5,3		
		25	6,0		
		30	6,0		
		35	6,0		
		40	6,0		
35	2,3	10	5,3	5,3 at top, battering ⅛ inch per foot for 20 feet; or 6 at top, battering ¼ inch per foot for 40 feet height.	11,8
		15	6,0		
		20	6,0		
		25	6,0		
		30	6,9		
		35	6,9		
		40	7,1		

TABLE

Of Dimensions of Arches and Piers for Elliptical Arches.

Span of arch in feet.	Depth of archstone in feet and inch.	Height of piers in feet.	Thickness of piers in feet and inches.	Thickness of piers at springing, with batter, in feet and inch.	Rise of arch in feet and inches.
40	2,7½	10	6,0	6,0 at top, battering ⅛ inch per foot for 20 feet: or 6,4½ at top, battering ¼ inch per foot for 40 feet.	13,4
		15	6,4½		
		20	6,9		
		25	6,9		
		30	7,1½		
		35	7,1½		
		40	7,6		
45	3,0	10	6,9	6,9 at top, battering ⅛ inch per foot.	15,0
		15	7,1		
		20	7,6		
		25	7,6		
		30	7,10½		
		35	7,10½		
		40	8,3		
50	3,4½	10	7,6	7,6 at top, battering ⅛ inch per foot.	16,8
		15	7,10½		
		20	8,3		
		25	8,3		
		30	8,7½		
		35	8,7½		
		40	9,0		
55	3,9	10	8,3	8,3 at top, battering ⅛ inch per foot.	18,4
		15	8,7½		
		20	9,0		
		25	9,4½		
		30	9,4½		
		35	9,9		
		40	9,9		
60	3,9	10	9,4½	9,4½ at top, battering ⅛ inch per foot.	20,0
		15	9,4½		
		20	9,9		
		25	10,2		
		30	10,2		
		35	10,2		
		40	10,6		

TABLE

Of Dimensions in Segmental Bridges of which the Rise is less than one-third of the Span.

Name of Bridge, &c.	Span in feet and inches.	Rise in feet and inches.	Depth of arch stone in feet and inches.	Height of piers in feet and inches.	Thickness of piers in feet and inches.	Name of Engineer, and Remarks.
Stanhope Street, London and Birmingham Railway .	25,0	2,6	2,4	- -	- -	R. Stephenson. Brick, with stone springers; abutments formed by arches, the vertical axis of which is tangent to extrados of bridge.
Stivichall and Hearsall, London and Birmingham Railway . . .	30,0	6,0	2,0	- -	- -	R. Stephenson. Stone abutments, 3,9 on rock.
Pesmes, France . . .	43,9	4,1	4,1	10,0	6,4	— Bertrand. Stone; thickness of abutments 12,9, which proved insufficient.
Weedon Viaduct, London and Birmingham Railway .	45,0	11,6	2,3	14,0	7,6	R. Stephenson. Brick, with stone springers.
Stirling	53,6	10,3	2,9 and			
,, second arches .	58,0	12,5½	3,6 at	15,0	9,0 at	Stone.
,, centre arch . .	60,0	13,6½	springing		top.	
Nemours	53,8	3,7	3,2½	18,0	7,5 at top.	Perronet.* Thickness of abutments 17,6, backed by 3 counterforts 18 feet in length.
Blisworth, London and Birmingham Railway . .	63,0	13,0	2,6	- -	- -	R. Stephenson. Stone arch abutting on rock.

* Perronet made his piers remarkably small at the springing; but they battered rapidly, and the footings covered a considerable area in proportion to that of the top of the piers.

Hutchison, Glasgow	65,0	8,8½	- -	- -	11,0 at top.	J. Rennie. Stone; abutments 37.
	74,6	11,9	3,9			
	79,0	13,4	- -	- -	12,0 at top.	
Over the Mersey, Grand Junction Railway	75,0	14,6	3,0	- -	10,0, bat. 1 in 5.	J. Locke. Stone.
Do., do.	42,0	7,6	2,0			
Staines-on-Thames	66,0	8,0	2,0	- -	9,0 at top.	J. Rennie. Stone; abutments 40, with a land arch of 10 span.
	74,0	9,0	2,6			
Concorde, Paris	75,5	6,4	3,5	22	9,7	Perronet. Stone; thickness of abutments 50 feet.
	85,3	7,7½	3,7			
	91,10	9,10	4,0			
Over Lea Cut, London and Blackwall Railway	87,0	16,0	4,1½	- -	- -	Brick, on stone springers.
Darlaston	86,0	13,6	3,6 9,0 at springing	- -	- -	J. Rennie. Thickness of abutments 20,9 in radiating courses; length of counterforts 20,9.
Rouen, France	85,3 101,8	10,8 13,9	4,9	18	10,6 at top.	Lemasson and Lamande. Abutments 59, with a land arch of 13 span, and 10 from ground to crown.
Wellington, at Leeds	100,	15,0	4,0 and 7,0 at springing on face.	- -	- -	J. Rennie. Abutments 30 feet, diminishing to 27 at springing; in radiating courses within; the *interior* arch stones average 3,0. Bramley Fall stone; 91 feet radius.
Stone at Allanton	75,	11,6	2,6 and 3,0 at springing	- -	- -	R. Stephenson. Red sandstone; radius of intrados 66.89, and of extrados 72.42.
Chester, over the Dee	200,	42,0	4,0 and 6,0 at springing	- -	- -	— Harrison. Equilibrated by G. Rennie.

68. The following is Ware's method of finding the extrados of an arch of equilibration. Having the span, intrados, and depth of arch at the crown, to find the extrados, divide A C, Fig. 59, into any number of parts, as at 1, 2, 3, 4, 5, 6, 7, 8, &c., and through these divisions draw, O, *a*, O 2 *b*, O 3 *c*, O 4 *d*, O 5 *e*, O 6 *f*, O 7 *g*, &c.; also through 1, 2, 3, 4, 5, 6, 7, &c., draw the verticals 1 *p*, 2 *p*, 3 *p*, 4 *p*, 5 *p*, 6 *p*, &c., and make each of these verticals equal to C D; through *p*, *p*, *p*, draw the horizontals *p a*, *p b*, *p c*, *p d*, *p e*, *p f*, &c., to cut O 1 *a*, O 2 *b*, O 3 *c*, O 4 *d*, &c.; and the points of intersection *a*, *b*, *c*, *d*, *e*, *f*, &c., will be the points through which the curve of intrados will pass; this first description refers to that side of Fig. 59, where the extrados is dotted.

69. To find the thickness of abutment; produce *p a*, *p b*, *p c*, *p d*, *p u*, *p t*, &c., and make *a y* equal to *p a*, *b x* equal to *p b*, *c w* equal to *p c*, *d v* equal to *p d*, and *e u* equal to *p e*, &c.; from *t*, *u*, *v*, *w*, *x*, *y*, let fall verticals; from *f*, perpendicular to 6 *f* draw *f o*; through *e*, perpendicular to 5 *e*, draw *e o*; through *d*, perpendicular to 4 *d*, draw *d o*, through *c*, perpendicular to 3 *c*, draw *c o*; through *o*, *o*, *o*, *o*, &c., which are the points of intersection of the last lines drawn, and the last verticals *let fall*, draw the curve *o*, *o*, *o*, *o*, &c., which will be the line of thrust; join O R, and bisect it at G, and from G at a centre, with radius G O, describe the curve *b* R; join *b* R by a straight line *b* R, which will give the limits of abutment; this method borders remarkably near practice; if from *b*, we let fall a vertical *b* T, S T will be the thickness of abutment, and V may be considered the point of limit for the counterfort, and the curve *o*, *o*, *o*, *o* V, the line to which the courses of masonry in the abutment should be perpendicular. Fig. 60 shows an elliptic arch extradosed; with the thickness of abutment found in the same manner, but in this latter instance the thickness of the abutments is rather in excess, at least at top.

70. Having the span and the rise of a segmental arch to find the radius; in Fig. 61, A B is the span and C D is the rise; let A B be S, and let C D, be V: required the radius; then,

$$R = \frac{V}{2}\left(1 + \frac{S^2}{4V}\right)$$

Or in figures, let C D, or V, the rise be 9 feet; and let A B, or S the span be 30 feet;
then

$$\frac{9}{2} = 4.50;$$

and

$$30^2 = 900;$$

and

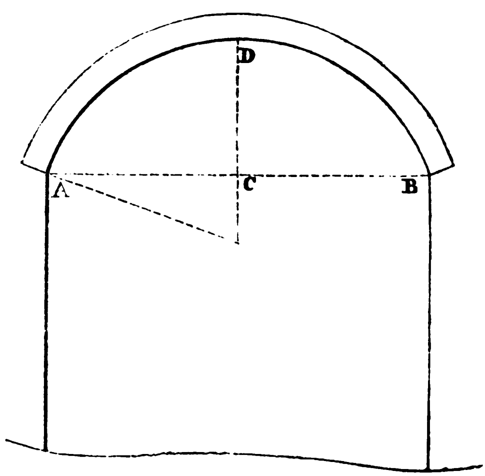
$$9^2 = 81 \times 4 = 324,$$

$$S^2 \text{ or } 900 \div 4\,V^2, \text{ or } 324 = 2.7777 + 1 = 3.7777;$$

and

$$\frac{V}{2} \text{ or } 4.50 \times 3.7777 = 16.999651, \text{ or radius required.}$$

Fig. 61.



Or the rectangle under the segments of one chord being equal to the rectangle under the segments of another, we may make use of the following rule:—

$$\frac{\left(\frac{S}{2}\right) \div V + V}{2} = R$$

or

$$\left(\frac{30}{2}\right)^2 = 225$$

$$\frac{225}{9} = 25; \text{ and } 25 + 9 = 34;$$

$$\frac{34}{2} = 17 = \text{Radius.}$$

71. At the commencement of this chapter the reader will find a table of the proportions for the different parts of bridges and viaducts, such as are generally used in practice; in these tables the dimensions given are for brick; beyond 35 or 40 ft. span, the construction of arches in brick is only met with in a few cases, as a great depth of arch becomes necessarily involved; the span of the elliptic arch at Maidenhead, on the Great Western Railway is 128 ft. the rise is 24 ft. 3 in. and the depth of arch is 5 ft. 3 in.

72. With regard to the width of the arch stones at the intrados we may take from $\frac{1}{3}$ to $\frac{1}{2}$ of the depth at the crown, remembering that the number of voussoirs must be an odd number, as one of them will be the key stone, and their number multiplied by their thickness should be equal to the length of the arc, allowance being afterwards made for mortar; the dimensions should be figured on the drawing, for the intrados and extrados, and the engineer should see that the arch stones are worked to those dimensions, within the limitsof practical means.

73. To rectify the arc of a circle, or to find the length of a circular line, either of the following rules are sufficiently near for practice:—

Let C be equal to the chord of the arc, or the span, A B, 30 ft., Fig. 62, and let c be equal to the chord of half the arc A C, 9 ft. and x the length of the curve required; then

$$x = \frac{8c - C}{3}.$$

or by figures

$$\sqrt{AD^2 + DC^2} = 17.4928557;$$

and

$$8c = 17.4928557 \times 8 = 139.9428557;$$

and

$$8c - C = 139.9428557 - 30 = 109.9428557;$$

and

$$\frac{8c - C}{3} \times \frac{109.9428, \&c.}{3} = 36.6709, \&c.;$$

and

$$x = 36.6709 = \text{length of arc.}$$

Or as before, putting C, for A B, span of 30 ft.; and c for C D, versed sine, or rise of 9 ft.; and x for length of curve required, we have

$$x = C + \frac{8c^2 C}{3C^2 + 2c^2}$$

or in figures,

$$\text{rise}^2, \text{ or } c^2 = 81;$$
$$c^2 = 81 \times \text{C or } 30 = 2430;$$

and

$$3\,\text{C}^2 + 2\,c^2 \text{ or } 2700 + 162 = 2862;$$

and

$$19440 \div 2862 = 6.7924;$$

and

$$\text{C} = 30 + 6.7924 = 36.7924 \text{ length of arc.}$$

74. And having found this length, if we divide by about one half the depth of arch stone, say 2 ft. on the face, we shall obtain the number of voussoirs or arch stones, and also have their dimensions at the intrados, allowance to be made afterwards for mortar; here reducing 36.79 to inches, we get 441 in., and 441 divided by 11.31 in. = 39, almost exactly, and nearer than we can ever obtain it in practice; $\frac{1}{16}$ of an inch is the least quantity masons can be expected to observe; we shall therefore have 39 voussoirs of 11.31 inches thickness at the intrados, and if we allow $\frac{1}{5}$ inch for the mortar joint, we shall have 10.91. For the thickness at the extrados, see page 86.

75. We have now the span, the rise, the radius, the depth of arch, the division of the arch into arch stones, the thickness of the piers, and the width of the abutment at the base, though circumstances will continually modify this dimension between $\frac{1}{4}$ and $\frac{1}{5}$ of the span; under 20 ft. it will be nearer $\frac{1}{5}$.

76. The practice of engineers varies very much with regard to the backing, or filling in of the spandrils, *a*, Fig. 62; our railway bridges are generally equally extradosed, that is the extrados is parallel to the intrados, though certainly not because it is the strongest form of extrados; sometimes the arch stones increase towards the springing, and the extrados is often then a curve of contrary flexure from about an angle of 45°; sometimes also the depth of voussoirs increase by a similar curve to that of the intrados, becoming at the springing of twice the thickness of the crown; this subject belongs exclusively to the study of bridges; the tables above given are for arches equally extradosed. The spandrils may be filled by solid masonry, surmounted by spandril arches, or by solid masonry and spandril walls, or by solid masonry alone; the object is to receive the thrust of the upper portion of the arch and of the load super-

imposed, and to dissipate vibration, and where spandril arches and spandril walls are used, relieve the upper portion of the arch from vertical pressure; in arches up to 50 ft. span, the spandrils may be filled in with solid masonry; and here practice varies very much also; in many cases it is scarcely as high as $\frac{2}{3}$ rise of the arch, as in the Congleton viaduct on the Manchester and Birmingham Railway, of 60 ft. span, 21 rise,* segmental arch of brick, 3 ft. thick, equally extradosed, and the engineer, G. W. Buck, is certainly sufficient authority to warrant similar practice in a similar case; we know also that it is the practice of other engineers of high standing for a sound knowledge of construction, and whose works are very numerous throughout the railways of England, who fill in the spandrils level with the intrados, and would do so in such a case as that mentioned above; we consider that the spandril over the centre of the pier may be filled in up to within a few inches, or a foot of the level of the intrados, and a line drawn from this point tangent to the extrados, will give the backing, Fig. 62 *a*; we are here speaking of an arch in which the versed sine is equal to $\frac{1}{3}$ of the span; in flatter segments the backing over the centre of the pier would be rather higher, say level with the intrados at the crown for a rise of $\frac{1}{5}$ of the span.

77. Still speaking of the same description of arch, we may proportion the depths of the springers in the following manner; from 20 to 30 ft. span, 1 foot for the depth of springer; from 30 to 35 ft. span, 1 foot 3 in.; from 35 to 40 ft., 1 foot 6 in.; 40 to 50 ft., 2 feet; 50 to 60 ft., 2 ft. 6 in. and 3 ft.; less dimensions, may be allowed for string courses; a good depth of string course acts like a chain over the spandril walls; make all mouldings plain, bold, and so weathered and throated, that water cannot lodge.

78. A transverse section through an arch should show dimensions between the faces of the arch, the thickness of spandrils, the dimensions of string courses, parapets and coping; and these dimensions should all be figured; where any of these parts are decorated by mouldings, enlarged or detailed drawings should be given, showing the centres of curves and the bevels; a section of wing walls near the pilaster should also be given,

* At least as shown in Brees' Railway Practice.

and where brick is the building material, care must be taken to count the dimensions by bricks and half bricks, or these dimensions have no real value beyond the drawing; the young practitioner must never lose sight of one important point on the subject of working drawings, that they are only preparatory to the construction of a building, and that this important point from ignorance or carelessness is so often neglected, that one or two dimensions having been taken the drawing becomes worthless; hence, a common observation amongst workmen, "who ever saw a working drawing that could be worked from;" an engineer in charge of works, should consider himself responsible for the value of working drawings, making, however, some allowance for unexpected circumstances; whether the material be stone or brick, iron or wood, a little thought, observation and study of material will guide him in giving instructions for working drawings, which may be worked from; and in setting out the dimensions on paper, he should consider himself as setting out the work itself; as regards the principal lengths, widths, and heights, a cross section to a large natural scale taken on the site *determined on*, will generally save him from blundering, as regards section, elevation, and plan; the neglect of this precaution will ensure two things, viz., a wide difference between the work constructed and the drawing, and the impossibility without making a fresh drawing, of setting off the quantities of work performed; it must not be supposed that an affectation of fastidious care is here pretended, involving useless trouble to others and loss of time, and, it must, on the contrary, be considered that we are alluding strictly to *practice generally*, and that experience and candour alone suggest these observations for those who are willing to be guided; *the rough and ready* school, and, in truth, the lazy school, may take their own course.

79. A few remarks on brick as a constructive material in arches may not be inappropriate; this building material is only employed in the construction of an arch from motives of economy, not only where stone is not easily attainable, but also to avoid the expenditure of cutting the arch stones to their true form; in this sense, also, bricks have the advantage of being more easily raised in moderate quantities, and from their small size of being more easily handled and placed; but compared to

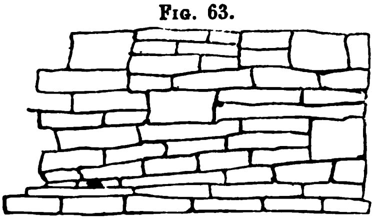
stone, brick is a frangible and porous material, at least that description of brick usually resorted to from motives of economy, and rain and frost too often perform quick justice on these defects, by fracturing and splintering the materials in the intrados, which, consequently, drop out, thus commencing the destruction of the arch, unless careful precautions be taken to prevent the access of surface water to the extrados, by covering the arch with an impervious material as good clay puddle, or asphalte *properly prepared and laid on.* Bricks, being in rectangular forms, would necessitate gauging to proportion their outer surface to the outer periphery of the ring, and this, economy puts out of the question; moreover, this expensive precaution in a large arch, comparatively speaking with regard to the size of bricks, would be almost useless in consequence of the small depth of a brick ring and of bond; the auxiliaries, therefore, to obtain the curve of the arch, are a series of wedges of mortar or cement, the latter of which, although more expensive than the first, is now generally used as the cementing matter; it is only after a time that this material acquires the hardness of the brick generally employed; and to gain this advantage the cement must be of a good average quality, well prepared and properly used; and much of this quality of soundness will depend on the proportions, purity, and grain of the sand, with which it is mixed; these observations are made very positively on sound data, close observation, and numerous experiments. However valuable a quick setting cement is in hydraulic masonry, in the construction of an arch, it is, by no means, so desirable, and a rather slowly setting cement is preferable from time being allowed from the commencement and completion of the arch, to the easing of the centres, when a certain degree of yieldingness in the cement is advantageous to the regular settlement of the arch, after which, the harder it becomes, the better we may consider the cement. A brick arch may be considerably strengthened by the introduction of sheet iron straps between the courses, by the arch resting on stone springers, and by facing with stone quoins, which should have a good length, say two feet, Fig. 77, and with a good bond; these quoins should have their soffits fair tooled, and they should underhang the bricks by a couple of inches, and have the edges chamfered off, when they act as drip-stones

and prevent rain water from gaining access to the brick work. In all constructions, however, whatever the material, whatever their purpose, we must be guided by circumstances, and not the least of these will be our means.

80. Much of the above observations will hold with regard to the stone voussoirs of an arch, but in a less degree, as the arch stones are cut to a radiating form, the intervening mortar is no longer of wedge shape, and the thickness of the mortar joint should only be such as to act as a cement, and entirely fill up vacuities between arch stones; the greater the span, and still more, the less the rise of the arch, the greater the necessity of strict adherence to this important point will be. With regard to the filling in of spandrils of railway arches, which are generally of only a moderate span, the work should be as sound as any other part, but appearance is not here requisite; pieces of brick may be introduced in brickwork, rougher materials may be used, but there should be abundance of mortar, and in this part of the construction, bricklayers and masons will introduce as little as possible, if they are not watched. In masonry, or stone work, there should be sufficient binders, and all the work should be well and closely packed; it must not be forgotten that, although this part of the construction is out of sight, it has to perform the duty of resisting the thrust of the upper portion of the arch tending to overturn the lower.

81. Ashlar and blocking course, or masonry composed of stones of two different sizes, large in one and smaller in the other, generally also compose the structure in the wing walls, but as far as these wings are concerned, where not on turnpike roads or principal thoroughfares, coursed rubble, Fig. 63, may be used with a considerable saving of expense, and a great increase of strength will be obtained by coursing any description of work vertically to the battering slope. The engineer will never display his talents and constructive knowledge with greater benefit to his employers or credit to himself, than by a judicious and considerate

Fig. 63.



application of the various kinds of masonry and brickwork to various circumstances, and in engineering work almost always heavy, the subject is of primary importance in an economical point of view alone.

82. From face to face of parapet, it is customary to give 28 and 29 feet, 2 feet 6 inches of which are occupied by two almost useless parapet walls, which, in every point of view, might be advantageously replaced by a cast-iron railing; the transverse sections, Figs. 64 and 65, will more fully explain the meaning of this; with the iron railing, fully sufficient space is maintained outside the rails, a more ornamental appearance is obtained, instead of 29 ft. for the width of arch, we have only 25 ft., thereby economising a considerable quantity of expensive masonry or brickwork in the arches, and in case of lofty piers in viaducts, this diminution of quantities, would become of still greater importance; by corbelling to a *small extent*, as shown on one side of Fig. 65, we may gain a greater space between the outer rail and the iron balustrade.

83. We will not extend beyond a few words our remarks on the centres of railway arches; centres must be viewed as the means by which the materials forming an arch are to be supported until the arch is keyed in, and also as the moulds by which the intended curve is given to the series of stones, bricks, &c.; designs for centres are not expected from the engineer, it being the business of the contractor to provide these, but it is distinctly the business of the engineer, to see that the centres employed be of correct form and dimensions, of sufficient strength for their intended purpose, and so framed as to be *practically* unyielding under the load they are to bear; it is, therefore, necessary that he should take this subject into general consideration in the superintendence of railway works, more particularly under certain important points presently to be pointed out, without the slightest pretension, however, to allude to bridges of vast span, or to those of very small rise, where the centres become of the last importance even in minute details of composition and construction. As soon as the voussoirs of the arch assume an inclination to the horizon, whereby the weight of the stone overcomes the friction between the connecting surfaces,

the arch stones then begin to bear upon the centres, which latter must be capable of bearing this increasing weight, and of keeping the stone upon its inclined bed; when a soft bed of mortar is interposed between two arch stones, this inclination to the horizon may be considered an angle of about 20 degrees,* after which every stone bears the more heavily on the centre, until the power of the weight becomes sufficient to force inwardly the sides or haunches of the centreing rib, and to force the crown upwards, unless the construction be such as to resist this pressure; and the flatter the arch, either in a segmental or elliptical curve, the more effective this pressure will be, and the greater, therefore, the requirements from the centres; when a vertical drawn through a centre of gravity falls without the lower voussoir, the whole stone may be considered as weight on the centre; even in small spans of 30 and 40 ft., this subject requires strict attention, as there can be no doubt that deficiency of strength in this direction, not from want of material, but ill disposition and bad workmanship, has occasioned many of the accidents to arches so prevalent during the last year, as well also as the haunches of arches being loaded prematurely; when a centre rib is thus upreared at the crown, a heavy load must be there applied to weight it back, but it is very doubtful in thus weighting the centre, whether we force it back into its original form; indeed this cannot be expected, and only an approximation to the first curve can be hoped for; a very little thought will make this apparent, and, therefore, also the necessity of attention to this subject. The greater the number of joints in the rib, the greater the liability to flexion, these joints being the points at which the parts of the rib pivot, and these, therefore, require support by framing, auxiliary timbers, strapping, &c.; the above must be considered the first requisite in a centre; next follow an economical erection, and an easy removal, and economy will be best observed by employing mostly timbers of the common scantlings, and in such manner that the timber may be employed for general purposes afterwards. In designing or inspecting centres, it is more particularly at the angle

* Tredgold says 34 degrees.

where the whole weight of the arch stones leaves, practically speaking, the lower voussoirs of the arch to rest entirely on the centre, that we must look for resistance to this weight, therefore, material should be disposed accordingly, and an angle of 50 or 55 degrees may be considered to be about this point generally, at least where the width of a voussoir is equal to about half the depth; centre ribs may be set at from 4 to 6 ft. apart, these being extreme limits, and care must be given to secure them from any lateral motion; on the centres come what is termed the lagging, which are narrow planks set across from rib to rib. The supports of centres that are raised high above the ground, as in lofty viaducts, require particular attention, as the great length of leverage renders them particularly liable to serious lateral motion from vibration or otherwise; in all cases the balks bearing the several ribs should be well braced together in the direction of the transverse section of the arch; it is a common custom to rest these supports on corbels projecting from the piers; but this must be considered more economical than beneficial.

84. The easing and striking of centres requires care and watchfulness, and, accordingly as the setting of the centre affords the ready means of doing this, so will be the facilities for obtaining a regular and steady settlement of the arch; since the voussoirs rest upon the centreing, they will descend as the centreing recedes from them, suddenly if the centre is suddenly removed, unequally at each side of the arch if the descent of the supporting centre be unequal, and this by fracture in some of the mortar joints if this cementing matter be dry, or by an unequal forcing out of the mortar if too soft; either of these degrees of induration being, therefore, least fit for the easing of the centres. Our business here is not the description of construction, or easing and striking of centres of vast span, for information on which the reader is referred to the works of the Rennies, Smeaton, Harrison, &c.

85. The means usually adopted for easing the centres of railway arches consists of double wedges, which being driven back equally at each end by men striking with mauls, allows the centre to descend as the wedges retire, and the quantity of

release, therefore, may be easily ascertained as the operation proceeds; the men performing this task generally know perfectly well what they are about, but it is as well to observe, that the great weight superimposed on these wedges during the construction of the arch forces the fibres of the wood together, occasioning at first great friction, which must not be overcome too suddenly and violently, as the result would be a shock; when the settlement of the arch is complete, the centre may be entirely removed.

86. Figs. 66 and 67 are longitudinal and transverse sections of an elliptical arch of 30 ft. span, with cast iron balustrades; the form of counterfort and backing is inferior to that of a similar arch given further on. Figs. 68 and 69 are through a semicircular arch; the longitudinal section has been given in another work, as being on the London and Birmingham Railway; but an arch so backed without spandril walls would not stand, the backing should be at least three feet higher.

87. Figs. 70 and 71 are sections through a bridge in cutting or over the railway, the inclination of the road being 1 in 34.28; in making the working drawings and setting out this description of bridge, the gradient stipulated for as the future inclination of the road requires strict attention, to avoid disputes with road trustees and land owners, who do not fail to take advantage of any error or discrepancy on this point, or on width between parapets.

88. Fig. 72, on the Weedon Viaduct, London and Birmingham Railway; we think the spandril arches would, in these days, be occupied by solid backing; and the drains down the piers would now be carried through the arch; the abutment is rather extensive.

89. Fig. 76. is a section on a viaduct on the Midlands; instead of spandril arches, fill up to 1,6 below the level of the intrados at the crown, and level off in the direction of the top of the intrados; Fig. 77 is proposed for a transverse section, in which are shown the stone quoins.

Figs. 80, 81, and 82, for a 2 ft. barrel culvert.

Figs. 83, 84, and 85, for a 3 ft. culvert.

Figs. 86, 87, and 88, for a 4 ft. culvert.

Figs. 89, 90, and 91, for a 5 ft. culvert.

Figs. 92 and 93, for a 10 ft. culvert; this work should be filled up with dry filling to 2 ft. below the crown, as there is some degree of weakness at the haunches.

Figs. 94 and 95, for an egg culvert for heavy ground.

Fig. 97, centre for 24 ft. span.

Fig. 98, centre 30 ft. span.

Fig. 99, centre for 40 feet span.

CHAPTER XI.

Wooden Bridges and Viaducts.

90. WOOD, as a material for the construction of bridges and viaducts may be selected in preference to stone or brick, on the score of economy, and from the comparative rapidity with which such structures may be erected; but it is of course very inferior to the last named materials as regards strength and durability; and in designing and constructing such works, the inherent defects of wood must as much as possible be counteracted. Experience has proved, that the most simple combinations of timber are superior for strength to complicated systems; and these have latterly become almost entirely abandoned. By *calculation*, a scientifically framed truss may be made; the almost impossibility in practice of making such a perfect assemblage of the timbers as the calculations would have been based upon, renders such complicated combinations unwise; moreover, to obtain even that degree of perfection of which practice is capable, we must resort to an excess of strapping, bolting, keying, morticing, and every description of jointing, which becomes very expensive, and when we have done all this, the destructive effects of rain, sun, and wind, increase in the very proportion of complication introduced in the system of construction; unavoidably, also, a considerable quantity of material is wasted, which might be profitably reserved for increase of strength under a more simple mode of treatment. The intention of a truss, composed of a multitude of timbers, is not only an equable distribution of the superimposed weight, but also a dispersion of the shaking and vibration resultant from the motion of weight; this, nothing but the most perfect workmanship could obtain, and all practical

men know the extreme difficulty of obtaining this, however great the expense incurred. In Colonel Emy's very clever work on carpentry, and in the work on bridges published by Mr. Weale, the student will find a variety of systems and combinations; but in this little work the author must be of few words.

91. For great spans, the laminated arch is unrivalled for strength and elegance; it is formed of planks laid one upon the other, breaking joint in length and breadth and bolted together. Colonel Emy, above mentioned, claims the invention, in 1819. From the tendency of the planks, which however appears to be but small, to spring back to their original straight line, the thrust of such an arch on piers or abutments, is no greater than that of a single beam. On this description of arch, originally applied to the construction of roofs, two distinct systems of bridge arches have been based; the one by the superposition of the platform on the laminated arch, and the second and best, by suspension from it. The following note of dimensions of viaducts of this description may not be here out of place.

Notes of Dimensions of some Laminated Arches.

Name of Viaduct, or Bridge.	Name of Engineer.	Span in feet and inches.	Rise in feet and inches.	Thickness of Rib in feet and inches.	Width of Rib in feet and inches.
Ouse Bridge, East Anglian Railway	J. S. Valentine	121,6	14,4	3,8	{ 2,9 / 2,2
Dinting Vale, Sheffield and Manchester	A. Jee	125,0	25,0	4,6	2,4
*Wellington, Dean, Newcastle, North Shields, and Tynemouth Railway .	J. & B. Green	120,0	36,0	3,9	1,10
Ouse Burn, do., do., Railway . . .	The same	116,0	32,6	3,6	1,10
West Durham . .	The same	79,0	13,0	2,3	1,5
Sechill	R. Nicholson	81,6	8,9	2,3	1,5
Newcastle - upon - Tyne and North Shields	The same	52,6	7,0	1,9	1,5

* In justice to Messrs. Green, we should have given priority, according to date, to their work; in fact, the Dinting Vale appears almost a fact-simile of the Willington Dean and Ouse Burn, with the exception of the rise being much less. *See* the Bridges published by Mr. Weale, Brees' Railway Practice, Third Series.

92. In the Sheffield and Manchester, Willington Dean, Ouse Burn, and West Durham, the platform of the railway is supported by struts or spurs, which rest upon the laminated ribs, which abut on cast-iron bed plates resting on stone piers; there are three ribs in each arch.

93. In the Sechill and North Shields, in which the laminated arches form flat segments, the platform is suspended from the arch by wooden ties strapped to the arch, and braced together laterally; the rib springs from a joggled cast-iron shoe, resting on the platform which surmounts stone piers.

94. In the Ouse Viaduct, on the East Anglian Railway, the platform is also suspended from the laminated rib; but, most judiciously, the engineer has suspended the platform by means of wrought-iron rods; the drawings, for which we are greatly indebted to Mr. Valentine's courteous liberality, are far preferable to any description we could give, and we will close the subject by referring the student to them, and annexing a few observations which appeared in the "Railway Chronicle of last October." "The viaduct over the river Ouse is 150 yards long, and consists of ten side openings of 30 ft. span each, with a single span over the waterway of 121 ft. 6 in. The method adopted to support the roadway over this great space, is by suspending the platform from three timber bows, each formed of three inch deals, firmly united together by oak trenails; the suspension rods are of wrought iron of the very best material and workmanship; each rod has been proved to be equal to a strain of 20 tons, and as there are 72 of these rods, the weight they are capable of supporting is 1,440 tons; but the greatest weight which they will be required to carry will not exceed 310 tons, the platform itself being 160 tons, and the greatest load that can be placed upon it being about 150 tons. The piers upon which the superstructure rests are built of Yorkshire stone, the foundations resting upon the solid gault at a depth of about 30 ft. below the top of the banks. Minute and careful admeasurements were taken by the government inspector to ascertain the strength of this bridge. *Four locomotive engines and tenders, and five waggons loaded with iron,* were placed upon it at the same time; but scarcely any deflection of the beams was perceptible; and whether the trains were at rest on the bridge,

or passing over it at full speed, there was not the least perceptible difference."

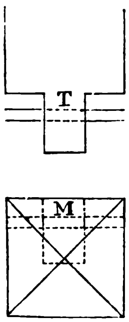
95. The drawings of the Ouse Bridge are so perfectly detailed, that no difficulty can occur in setting out any design of this description, by copying or changing, as future experience may suggest. The above note of dimensions will also be some guide in deciding on the number of planks of which the rib is to be composed. At present, as far as we are aware, 125 ft. is the greatest span we have in this description of arch. Specification page 97.

96. The Ladykirk and Norham bridge over the Tweed, J. Blackmore, Engineer, is composed of two arches of 190 ft. span each, rise 17 ft. Each arch consists, first of a rib, of three thicknesses of 6 in. planking at the crown, and the number of thickness is increased one by one towards the springing where the thickness of the rib consists of 8 courses of 6 inch planking; above this arch comes the platform, resting on the summit of the above rib; about 7 ft. above the platform comes another rib, of 110 ft. span and of about 5 ft. rise, the springing of this second arch being over the middle of a centre pier 20 ft. thick; this second rib consist of 7 courses of 6 in. planking at the crown, diminishing one by one towards the springing, where it consists of a single plank; the ribs are connected by 14 struts, each strut strapped at top and bottom to the ribs, and there are 14 braces connecting the struts; these struts and braces abut both on the upper and low ribs at the increase in thickness of planking. This design possesses the merit of originality, but we have only introduced this short description of it on account of the great span, and to suggest that in a similar case the upper rib be brought down and united to the lower one, and that it be formed of 3 instead of 6 inch thicknesses; the rib, however, should be made 5 ft. 6 in. thick, and 1 ft. 6 in. broad. Where the rise is only $\frac{1}{8}$th or less of the span, an increase of thickness at the springing is unnecessary.

97. The openings of viaducts are seldom under 30 ft., and as wood is not used for elegance or durability, but from motives of economy, it is fortunate that a very simple construction answers every purpose required, we mean that shown in continuation of the Ouse Bridge; it has been very extensively used, and expe-

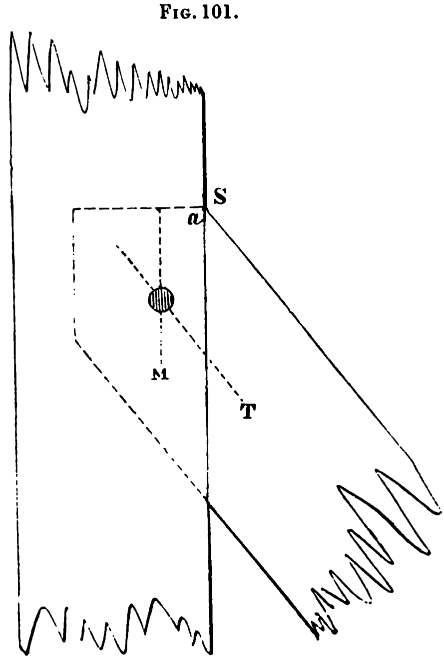
rience therefore recommends its continuence. In the drawings referred to, all that is wanted for the setting out of working drawings will be found. The reader will remember that strength of connection between the trusses tranversely is quite as necessary as the strength required in the form of the truss itself, and this will be effected by transverse ties and braces.

Fig. 100.



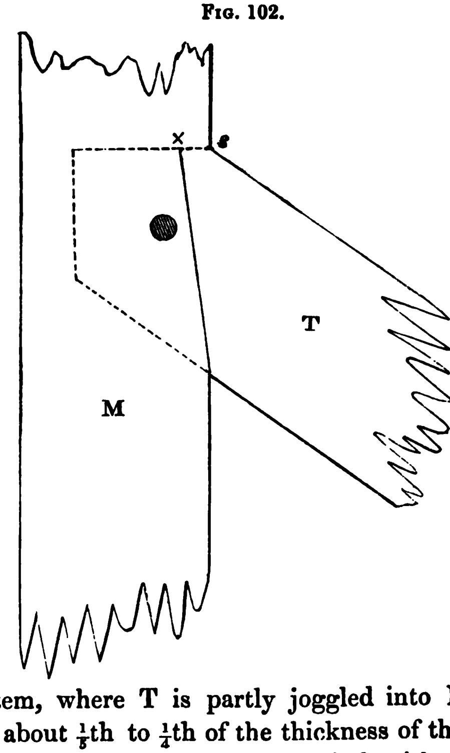
98. A few words on details may be of some service. Timbers are connected by various descriptions of joints, the most simple being generally the best, particularly for our purposes.—Fig. 100 shows tenon and mortice; T the tenon, M the mortice. The thickness of a tenon is made one-third the thickness of the timber on which it is cut, and the size of the mortice of course corresponds to the dimensions of the tenon; the depth of a mortice should exceed a little that of the tenon, as the perfection of the work so is the value of the joint; the shoulders of the tenon should be exactly in one place, and perfectly perpendicular to the axis of the timber; where acting by suspension, little depth is required if a strap be

Fig. 101.



added; an oak trenail should be driven through the timbers, the holes being bored after the tenon is in the mortice; the diameter of a trenail should be $\frac{1}{4}$th the thickness of the tenon, and the hole bored for its reception should be at $\frac{2}{3}$ds from the end of the tenon, as shown in the figure; but the value as regards the strength of a tenon and mortice should be independent of the trenail. The above is a rectangular mortice and tenon. Fig. 101 shows an oblique joint of this description, and it is believed explains itself. The above description of joint, though common, is not the best of the kind, the timber T being weak at *a*, and liable to fly; Fig. 102 is a

Fig. 102.

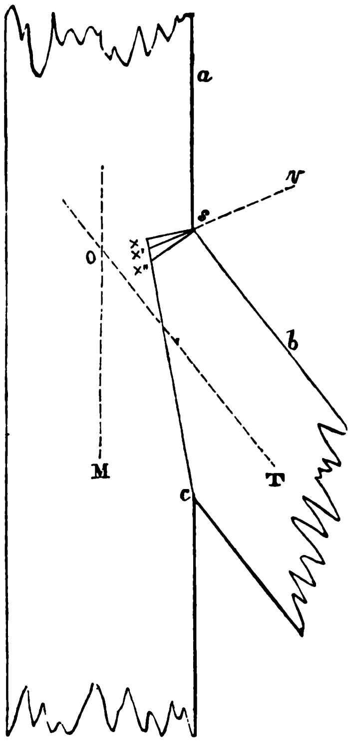


better system, where T is partly joggled into M, and *s x* is made from about $\frac{1}{5}$th to $\frac{1}{4}$th of the thickness of the piece M.

99. In setting out a joint of this kind, with a single joggle and no tenon and mortice, to find the direction of *s x*, Fig. 103; draw the central axes of the timbers, and *o s* will give the direction of *s x*; or divide the angle *a s b*, and the line *s v* will give the direction of *s x'*; or make *s x* perpendicular to *s b*; or from

c as a centre with radius *c s*, describe an arc, on which set off

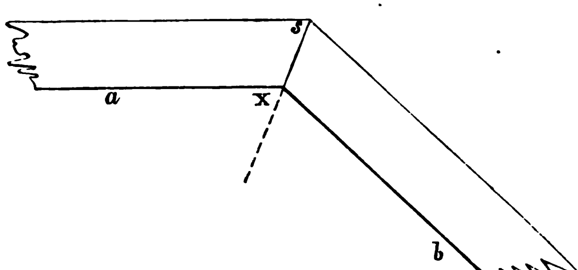
Fig. 103.



from $\frac{1}{4}$th to $\frac{1}{5}$th of the thickness of the timber M; it must not be forgotten that too sharp an angle at *x* is likely to make M fly at *x*. To find the direction of *s x*, in timbers abutting end to end, Fig. 104, divide the angle *a x s*, which will give the direction of *s x*.

100. It is always expensive to obtain timbers of large scantlings and great length; and when a beam beyond 24 ft. or thereabouts is required, we have generally recourse to scarfing, which, it is unnecessary to add, is a joint in which the ends of the timbers are cut and overlapped so as to form one in appearance. Some persons are partial to complicated scarfs; but we have no greater faith in them than in complicated trusses, much for similar reasons, and because so much hacking of the timbers must weaken it; also they become very expensive. In a scarf it is evident, that the bear-

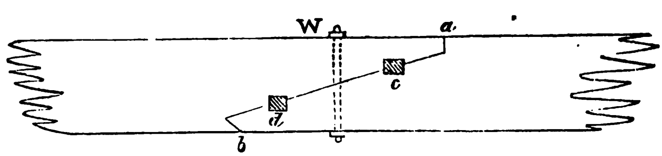
Fig. 104.



ing surfaces have to support the strain, and therefore the greater

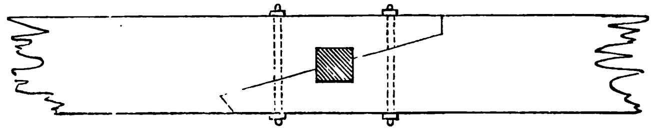
the quantity of surface the greater the strength, provided the best form be given; therefore also a long scarf is stronger than a short one, for the same reason that any strength at all is gained by a scarf, but a great waste of timber and much workmanship are involved. One important consideration, and which should never be lost sight of, is the strain to which a scarf will be exposed, compression or tension. Scarfs are greatly strengthened by iron bolts and oak keys; where the surfaces of the scarfing are square, iron bolts are preferable to keys, and the contrary where the jointing surfaces are oblique to the fibres of the wood. Let Fig. 105 be a beam scarfed at W, where it is

Fig. 105.



exposed to a strain from the weight W; the upper portion of the beam is exposed to compression, the rectangular bearing *a*, is therefore the most appropriate, as an acute angle formed by a line parallel to *b*, would, on the beam being compressed, act like a wedge, and tend to make the upper portion of one beam fly; but this is reversed at *b*, which would tend to open by tension. Of the keys *c* and *d*, the first would be under compression, and the latter would be loosened; but being near the neutral line, the tightening and loosening would be comparatively small, unless the beam were loaded beyond the bounds of prudence; also *c*, under compression, would tighten the beam at *a*, and though *d* would not do the same at *b*, the bevel joint must prevent any evil results. Whether we have one, two, or more keys, the single or aggregate depth should

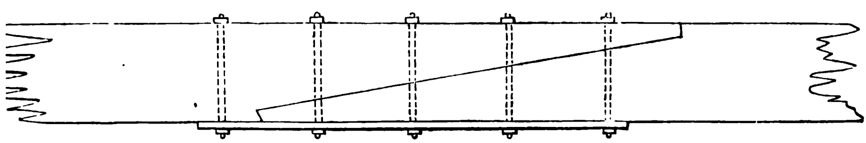
Fig. 106.



not exceed $\frac{1}{3}$rd the depth of the beam, neither should they be too violently tightened when driven. This scarf is short,

and we may add considerable strength by a bolt at W; and it would be better still to place a bolt at *c* and at *d*, and the key in the centre as at Fig 106. Fig. 107 is strong enough for

Fig. 107.



most purposes; it need scarcely be observed, that the further the scarf may be from the points of bearing, the greater the strength required; bolts should never be placed too near the end of a beam. Wrought iron straps are great auxiliaries of strength, and may be very advantageously used in connecting timbers, whatever may be the joint, provided always that tension be the strain to be resisted. It has been very cleverly remarked, that "a skilful carpenter never employs many straps," &c.; but however skilful a carpenter may be, he cannot prevent the effects of atmospheric influence, neither can he give to comparatively new wood the properties of well seasoned timbers. No man who knows any thing about designing in wood, would consider straps as principles of strength in his constructions; but as fastenings, as auxiliaries, they are perfectly admissible, of course in moderation, and are becoming daily more in use. Before use, straps, and indeed all iron work, should be heated to a blue heat, and struck over with raw linseed oil; this is far preferable to paint as preventative to rust, and is in accordance with the practice of Smeaton. A strap 1 in. wide may be made $\frac{1}{4}$ thick; $1\frac{1}{2}$ wide, $\frac{3}{8}$ thick; 2 in. wide, $\frac{7}{16}$ thick. Cast iron plates and shoes are also very useful to receive or to equalize the thrust from the ends of butting timbers, the first particularly where employed as a connecting surface between the ends of timbers, which from shrinkage, defect of workmanship, or otherwise, may come to bear upon opposite angles, instead of the whole area of their *intended* connected surfaces.

101. The truss shown in connection with the Ouse bridge has already been referred to for a 30 ft. bay; beyond this span we should not like to trust to a single pile for the pier; by widening the pier, or rather by constructing a pier, instead of

using a single pile, and by corbelling over it, the truss would be sufficient for a 35 ft. span; for 40 or 45 ft., four struts may be applied instead of two, and they may, if considered necessary, be strengthened by ties. As regards the piers, too much depends on circumstances connected with the nature of the natural foundation, to recommend any particular plan, as according to these circumstances it will be advisable to build entirely of wood or of masonry and wood; it will not be forgotten that wood exposed alternately to wet and dry cannot last very long, and this therefore will be one reason for employing stone or brick in water or marshy ground; on the other hand, weak ground will cause wooden piers to be preferable, and sometimes it may be advisable to make a wooden pier occupy an area of considerable extent, in order to spread the effect of a superincumbent weight over a greater surface, and thereby, to a certain degree, neutralize this effect; such may be the case in going over deep peaty ground.

102. This subject may now be concluded by practical illustrations of the rules for ascertaining the strength, or determining the scantlings of timber.

103. *To ascertain the cohesive strength of timber*, or the tension it will bear, when the weight acts in the direction of the axis of the timber multiply the area in inches by the proper tabular number in the table of specific gravities.

104. To find the weight that will tear asunder a piece of fir $4'' \times 4''$; we have here 16 square inches, and the tabular number is 9500; then $9500 \times 16 = 152{,}000$ lbs. one fourth of which would be taken in practice for a perfectly safe load, or 38,000 lbs.

105. Having the load to find the scantling, divide the load by the tabular number; as, let the load be 38000 : $\frac{38000}{9500} = 4''$, for the side of the scantling.

106. *To find the strength of a beam fixed at one end and loaded at the other*, multiply continuously the sectional area by the depth, by the constant of strength in the same table as the former constant, and divide by the length, all in inches; if the beam is inclined, the length will be the horizontal distance between the ends, of course not including the quantity of bearing, as of tailing into a wall.

107. To find the strength of a beam of Memel 10 ft. long, 5 in. wide, and 7 in. deep; $5 \times 7 = 35 =$ sectional area; 35×7 depth $= 245 \times 1730$, constant of strength $= 416850$; and this divided by the length in inches gives 3473 lbs. nearly; but this would be the breaking weight, only $\frac{1}{3}$ of which should be taken, or 1157 lbs. as the weight to be borne without straining the timber; and twice this load may be taken if the weight is to be distributed over the beam.

108. Given the depth, and length, and the load, to find the breadth; as above let the length be 10 ft., the load 1157 lbs., the depth 7; and the timber of the same description; multiply continuously the weight, by 4, by the length in inches, and divide by 1730 the constant multiplied by the depth 7; the product will be the sectional area, which by divide the depth 7.

109. Given the breadth, the bearing, and the load, to find the depth; multiply the weight by 4, by the length in inches, and divide the product by the constant multiplied by the breadth; and the square root of the quotient will be the depth.

110. *To find th estrength of a beam fixed at the ends and loaded in the middle;* multiply continuously the breadth $\times$ 6 $\times$ the square of the depth $\times$ by the constant, and divide by the length; as to find the strength of a beam of Riga 20 ft. long, 13 in. square; we shall find $\frac{13 \times 6 \times 13^2 \times 1050}{240} = \frac{57671}{3} = 19223$ lbs. in the middle, and twice this distributed over the beam.

111. The above rules are for permanent weights.

112. We may shorten the calculations by dividing any of the constants by 3, which will save the trouble of reducing the feet to inches; in the column for constants of elasticity, this has been done; calculations of this kind are generally made with the constants so reduced.

113. The above rules are mostly according to Professor Barlow's formulæ; and the constants are obtained by the formula

$$\frac{l\,W}{4\,b\,d^2} = \text{the constant,}$$

where l is the length in inches,

W the breaking weight,
b the breadth,
d the depth.

N

A batten is 2″½ × 7″.

A deal is 3″ × 9.

A plank is 3″ × 11″; above this size flat timber is termed a slab.

Scantling is a term used to express sectional dimensions of timber; it is also applied to quartering under five inches square.

Logs are about 13″ square and under.

A bulk is above 13″ inches square.

CHAPTER XII.

Cast Iron Girders.

114. In a former part of this work will be found a table of deflections on girders; and the reader will find matter of interest in comparing this table with Mr. Hodgkinson's valuable work on the strength of cast iron; according to the rules and data given by this gentleman, it is usual to calculate the strength of cast iron girders, and to determine their dimensions.

115. All other dimensions remaining the same, the strength is nearly in proportion to the sectional area of the bottom flange and in similar girders varying only in depth, the strength is nearly as the depth. The formula from which the constant is deducted, is $W = \frac{adC}{l}$, in which W is the breaking weight, *a*, the sectional area of the bottom flange taken in the middle, *d*, the whole depth of the beam, and *l* the length of the beam; from this we obtain $C = \frac{lW}{ad}$.

116. At page 445 of the second part of his work "Tredgold on the strength of Cast Iron," Mr. Hodgkinson has reduced into two tables a number of constants for girders cast erect and cast on the side, in which the proportions of the top flange, the bottom flange and the web vary; for a mean of constant in girders cast erect, he takes 536 cwt., and cast on their side 514 cwt., it is usual to take 514 cwts. reduced to tons, and leaving out the decimals. And this is applied in practice to girders having their bottom flange 6 times the area of the top flange.

117. The following is a practical rule for calculating the dimensions of railway girders. Multiply the length of bearing by 3, and take the product for a breaking weight, in tons, in the

centre; this, however, may be proportioned in any other way consistent with circumstances; unless indeed, for very great openings it is too much, even taking into consideration the uncertainty of cast iron. For some time past, however, the tubular girder has been substituted for spans exceeding 40 ft., where we are restricted as regards headway; for spans under 40 ft., we may for the breaking weight take 2 tons per foot of opening, which is, of course multiplying the bearing by 2. As an example we will take a 30 ft. span, $30 \times 2 = 60$ for breaking weight in tons, and if we intend to make use of Mr. Hodgkinson's rules, we should endeavour to obtain at least some approximation to the proportions of his models. In table II, pages 432 and 434, under experiment 4, he gives a model of the following proportions, 7 ft. bearing, 6″.93 depth of beam, $2''.25 \times .34 = .765$ area of top flange, and $6''.05 \times .75 = 4''.5375$ area of bottom flange.

$$\overset{\text{ft.}}{7} \text{ or } \overset{\text{in.}}{84} : 6.93 :: \overset{\text{ft.}}{30} \text{ or } \overset{\text{in.}}{360} : \overset{\text{in.}}{29};$$

then 29 neglecting decimals will be the depth of our girder; now putting as before, a, for the area of the bottom flange, d, for the depth of the beam, 25 for the constant, l for the length of the beam, we have

$$\frac{a\,d\,25}{l} = \text{W};$$

substituting our quantities, which are in inches and tons, we have

$$\frac{a \times 29 \times 25}{360} = 60 \text{ tons, the breaking weight};$$

or

$$a \times 29 \times 25 = 21600,$$

or

$$725\,a = 21600;$$

whence for a, the area of the bottom flange, we find 29″.79; call it 30″.

118. In the model girder, already mentioned, the proportion of the area of the bottom flange, to the whole area of beam is as 4.537 : 7.60, making a little allowance for the hollows filled up, where the first is considerably more than half the latter; were we to proportion our dimensions similarly, we should have too little metal for the web or middle part, taking into consideration

the imperfections of large castings; let us, therefore, as is most usual, consider the area of the bottom flange, as one half of the area of the whole beam, and we shall have 60 for the sectional area, in inches, of the whole beam; in the model beam, the area of the bottom flange is as nearly as possible, six times the area of the top; for girders bearing dead weight, this is sufficient; but for railway girders, liable more or less to shocks, we must take for the area of the top flange $\frac{1}{3}$ of the area of the bottom flange; one-third of 30″ is 10″, which will be the area of the top flange; and 10″ + 30″ = 40″; 60″, the whole sectional area, — 40″ = 20″ for the web; we must now find the thicknesses of the flanges, and of the web; in the model, above quoted, the length of the bottom flange is 6″.05, and the thickness .75; this proportion we could not adapt, and we must assume a practical dimension; if we make it 2 in., our breadth of flange will only be 15, for 15 × 2 = 30 area of bottom flange; this would do very well for a vertical dead weight, but is not sufficient for the motion of a locomotive; but we may take 1″$\frac{1}{2}$; and we shall have 20 in. for the breadth, and 1$\frac{1}{2}$ in. for the thickness of the bottom flange; for the top flange, we may take 8″ × 1″.25 = 10 area of top flange; we have now to apportion the dimensions of the web; the depth of the bottom flange is 1$\frac{1}{2}$, and depth of top flange 1$\frac{1}{4}$, which will give 2$\frac{3}{4}$, which deducted from 29, leave 26$\frac{1}{4}$ for the depth of the web, of which the thickness cannot be less than 1 in., imperceptible, and, indeed, unavoidable imperfections considered; this will give 26$\frac{1}{4}$ for the area in inches of the web instead of 20; we have, therefore, selected a model of too great depth for our span, if we restrict ourselves to twice the area of the bottom flange for the whole of the sectional area; we will now assume 2 ft. or 24 in., then

$$\frac{a \times 24 \times 25}{360} = 60 \text{ tons, the breaking weight,}$$

or,

$$a \times 24 \times 85 = 21600,$$

or,

$$600\,a = 21600,$$

whence for a, the area of the bottom flange we obtain 36 in.; and

$$\frac{36 \times 24 \times 25}{360} = 60 \text{ tons.}$$

36″ × 2 = 72, equal to the whole of sectional area, and $\frac{36}{3}$ = 12 sectional area of top flange; 36 + 12 = 48 = areas of top and bottom flanges, for the thickness of the bottom flange, we may take 1½ in., and the breadth of the flange will be 24 in.; 24 × 1½ being 36; and 8 × 1½ = 12, and we may, therefore, take 1½ for the thickness of the top flange.

1½ thickness of the top flange,
and 1½ do. of the bottom do.
3

24, depth of girder, — 3 = 21, for the depth of the web;

and 36 area of the bottom flange,
and 12 do. of the top do.
48

72, the whole sectional area, — 48 = 24 = area of the web, which is 21 deep, and which we may, therefore, make 1 $\frac{3}{16}$ thick.

119. We will now suppose, that we had made the web of the former girder 1 in. thick, we should have for its area 26¼; this + 30 + 10, the areas of the top and bottom flanges, would give 66¼ for the whole sectional area, instead of 72, as in the second case, and if we could ensure sound castings and good metal, we should prefer the former, on the score of economy; but if this cannot be most positively ensured, both by superintendance, rigid examination, and testing of the beams, it would be better to take the larger dimensions. Girders should be connected transversely by tie rods, bolted to side brackets cast with the girders at about every 2 ft. apart.

120. During the past year some interesting experiments were made by Mr. Richard Roberts, formerly of the firm, "Sharp and Roberts," to ascertain the comparative value of wrought iron tension rods, applied to strengthen cast-iron girders; from these experiments he found that when the larger flange was lowermost, the girders bore as much weight without the tension rods as with them, the breaking weight being a little above 14 cwt.; but the beams being inverted, that is the larger flange being uppermost, and the tension rods applied, the breaking weight was from 40 to 42 cwt.; the increase of strength from change of position, being nearly threefold.

121. In designing for cast iron, we must never for a moment lose sight of its being the most treacherous material we

have to deal with; cast of excessive thickness, it has been known to break under, comparatively speaking, a most trifling pressure, and yet when the fractured pieces were tested, they were found to be considerably above average strength. Again, a very slight blow has been known to break a girder which had for a long time borne the rapid passage of heavy trains; hence, ample dimensions are absolutely necessary, as well as an experienced selection of the kind of iron used, and careful superintendence during the casting and the testing.

ERRATUM.

Fig. 78, *for* "4,0" *read* "6,0."

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TABLE OF GRADIENTS.

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
10	6.6	66.	528.	10
11	6.	60.	480.	11
12	5.5	55.	440.	12
13	5.0769	50.76	406.15	13
14	4.7144	47.14	377.14	14
15	4.4	44.	352.	15
16	4.1243	41.24	330.	16
17	3.8823	38.82	310.58	17
18	3.6	36.	288.88	18
19	3.4736	34.73	277.89	19
20	3.3	33.	264.	20
21	3.1427	31.42	251.42	21
22	3.	30.	240.	22
23	2.8687	28.68	229.56	23
24	2.7499	27.49	220.	24
25	2.64	26.40	211.20	25
26	2.5384	25.38	203.07	26
27	2.4437	24.43	195.55	27
28	2.3562	23.56	188.57	28
29	2.2757	22.75	182.06	29
30	2.2	22.	176.	30
31	2.1290	21.29	170.32	31
32	2.0625	20.62	165.	32
33	2.	20.	160.	33
34	1.9411	19.41	155.29	34
35	1.8854	18.85	150.85	35
36	1.8333	18.33	146.66	36
37	1.7837	17.83	142.70	37
38	1.7367	17.36	138.94	38
39	1.6923	16.92	135.38	39
40	1.65	16.50	132.	40
41	1.6097	16.09	128.78	41
42	1.5714	15.71	125.71	42
43	1.5348	15.34	122.79	43
44	1.5	15.	120.	44
45	1.4666	14.66	117.33	45
46	1.4347	14.34	114.80	46
47	1.4042	14.04	112.34	47
48	1.375	13.75	110.	48
49	1.3469	13.46	107.75	49

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
50	1.32	13.20	105.60	50
51	1.2941	12.94	103.52	51
52	1.2692	12.69	101.53	52
53	1.2452	12.45	99.62	53
54	1.2222	12.22	97.77	54
55	1.22	12.2	96.	55
56	1.1785	11.78	94.28	56
57	1.1578	11.57	92.63	57
58	1.1379	11.37	91.37	58
59	1.1186	11.18	89.49	59
60	1.1	11.	88.	60
61	1.0819	10.81	86.55	61
62	1.0645	10.64	85.16	62
63	1.0476	10.47	83.80	63
64	1.0312	10.31	82.50	64
65	1.0152	10.15	81.23	65
66	1.	10.	80.	66
67	.9850	9.85	78.80	67
68	.9705	9.70	77.64	68
69	.9565	9.56	76.52	69
70	.9428	9.42	75.42	70
71	.9295	9.29	74.36	71
72	.9166	9.16	73.33	72
73	.9041	9.04	72.32	73
74	.8918	8.91	71.35	74
75	.88	8.80	70.40	75
76	.8684	8.68	69.47	76
77	.8571	8.57	68.57	77
78	.8461	8.46	67.69	78
79	.8354	8.35	66.83	79
80	.825	8.25	66.	80
81	.8148	8.14	65.18	81
82	.8048	8.04	64.39	82
83	.7951	7.95	63.61	83
84	.7857	7.85	62.85	84
85	.7764	7.76	62.11	85
86	.7674	7.67	61.39	86
87	.7586	7.58	60.69	87
88	.75	7.5	60.	88
89	.7415	7.41	59.32	89

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
90	.7333	7.33	58.66	90
91	.7252	7.25	58.02	91
92	.7173	7.17	57.38	92
93	.7096	7.09	56.77	93
94	.7021	7.02	56.16	94
95	.6947	6.94	55.57	95
96	.6875	6.87	55.	96
97	.6804	6.80	54.43	97
98	.6734	6.73	53.87	98
99	.6666	6.66	53.33	99
100	.66	6.60	52.80	100
101	.6534	6.53	52.27	101
102	.6470	6.47	51.72	102
103	.6411	6.41	51.26	103
104	.6346	6.34	50.77	104
105	.6285	6.28	50.28	105
106	.6226	6.22	49.81	106
107	.6168	6.16	49.34	107
108	.6111	6.11	48.88	108
109	.6055	6.05	48.44	109
110	.6	6.	48.	110
111	.5945	5.94	47.56	111
112	.5892	5.89	47.14	112
113	.5840	5.84	46.72	113
114	.5789	5.78	46.31	114
115	.5739	5.73	45.91	115
116	.5689	5.68	45.51	116
117	.5641	5.64	45.12	117
118	.5593	5.59	44.74	118
119	.5546	5.54	44.37	119
120	.55	5.50	44.	120
121	.5454	5.45	43.63	121
122	.5409	5.40	43.27	122
123	.5365	5.36	42.92	123
124	.5322	5.32	42.58	124
125	.528	5.28	42.25	125
126	.5238	5.23	41.92	126
127	.5197	5.19	41.57	127
128	.5156	5.15	41.24	128
129	.5116	5.11	40.92	129

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
130	.5077	5.07	40.60	130
131	.5038	5.03	40.29	131
132	.5	5.	40.	132
133	.4963	4.96	39.70	133
134	.4925	4.92	39.40	134
135	.4888	4.88	39.10	135
136	.4852	4.85	38.81	136
137	.4817	4.81	38.53	137
138	.4782	4.78	38.26	138
139	.4748	4.74	37.98	139
140	.4714	4.71	37.71	140
141	.4680	4.68	37.44	141
142	.4647	4.64	37.16	142
143	.4615	4.61	36.88	143
144	.4583	4.58	36.66	144
145	.4552	4.55	36.42	145
146	.4520	4.52	36.17	146
147	.4489	4.48	35.91	147
148	.4459	4.45	35.66	148
149	.4429	4.42	35.41	149
150	.44	4.40	35.20	150
151	.4370	4.37	34.96	151
152	.4342	4.34	34.72	152
153	.4312	4.31	34.47	153
154	.4285	4.28	34.28	154
155	.4258	4.25	34.06	155
156	.4231	4.23	33.84	156
157	.4204	4.20	33.62	157
158	.4178	4.17	33.40	158
159	.4152	4.15	33.20	159
160	.4126	4.12	33.	160
161	.4100	4.10	32.79	161
162	.4075	4.07	32.58	162
163	.4049	4.04	32.38	163
164	.4024	4.02	32.18	164
165	.4	4.	32.	165
166	.3975	3.97	31.81	166
167	.3952	3.95	31.62	167
168	.3928	3.92	31.43	168
169	.3905	3.90	31.24	169

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
170	.3882	3.88	31.05	170
171	.3859	3.86	30.86	171
172	.3836	3.83	30.68	172
173	.3813	3.81	30.51	173
174	.3793	3.79	30.33	174
175	.3770	3.77	30.17	175
176	.3748	3.74	30.	176
177	.3726	3.72	29.83	177
178	.3705	3.70	29.66	178
179	.3687	3.68	29.49	179
180	.3666	3.66	29.33	180
181	.3646	3.64	29.17	181
182	.3626	3.62	29.01	182
183	.3606	3.60	28.85	183
184	.3586	3.58	28.69	184
185	.3568	3.56	28.53	185
186	.3548	3.54	28.37	186
187	.3529	3.52	28.22	187
188	.3510	3.51	28.07	188
189	.3491	3.49	27.93	189
190	.3473	3.47	27.78	190
191	.3455	3.45	27.64	191
192	.3437	3.43	27.50	192
193	.3419	3.41	27.36	193
194	.3402	3.40	27.22	194
195	.3385	3.38	27.08	195
196	.3368	3.36	26.94	196
197	.3351	3.35	26.80	197
198	.3333	3.33	26.66	198
199	.3316	3.31	26.53	199
200	.33	3.3	26.40	200
201	.3284	3.28	26.27	201
202	.3267	3.26	26.14	202
203	.3251	3.25	26.01	203
204	.3235	3.23	25.88	204
205	.3219	3.21	25.75	205
206	.3203	3.20	25.62	206
207	.3187	3.18	25.50	207
208	.3172	3.17	25.38	208
209	.3157	3.15	25.26	209

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
210	.3142	3.14	25.14	210
211	.3127	3.12	25.02	211
212	.3113	3.11	24.90	212
213	.3098	3.09	24.78	213
214	.3084	3.08	24.66	214
215	.3069	3.06	24.55	215
216	.3055	3.05	24.43	216
217	.3040	3.04	24.32	217
218	.3026	3.02	24.21	218
219	.3013	3.01	24.10	219
220	.3000	3.	24.	220
221	.2986	2.98	23.90	221
222	.2972	2.97	23.79	222
223	.2959	2.95	23.69	223
224	.2946	2.94	23.58	224
225	.2932	2.93	23.47	225
226	.2920	2.92	23.36	226
227	.2907	2.90	23.26	227
228	.2894	2.89	23.16	228
229	.2882	2.88	23.05	229
230	.2869	2.86	22.95	230
231	.2856	2.85	22.85	231
232	.2844	2.84	22.75	232
233	.2831	2.83	22.65	233
234	.2819	2.81	22.56	234
235	.2807	2.80	22.47	235
236	.2796	2.79	22.37	236
237	.2784	2.78	22.27	237
238	.2772	2.77	22.18	238
239	.2761	2.76	22.09	239
240	.2750	2.75	22.	240
241	.2738	2.73	21.90	241
242	.2727	2.72	21.88	242
243	.2715	2.71	21.77	243
244	.2704	2.70	21.66	244
245	.2693	2.69	21.55	245
246	.2682	2.68	21.46	246
247	.2673	2.67	21.37	247
248	.2661	2.66	21.28	248
249	.2650	2.65	21.20	249

TABLE OF GRADIENTS.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
250	.2640	2.64	21.12	250
251	.2629	2.62	21.04	251
252	.2618	2.61	20.96	252
253	.2609	2.60	20.87	253
254	.2598	2.59	20.79	254
255	.2588	2.58	20.71	255
256	.2577	2.57	20.63	256
257	.2567	2.56	20.54	257
258	.2559	2.55	20.45	258
259	.2548	2.54	20.38	259
260	.2538	2.53	20.30	260
261	.2528	2.52	20.23	261
262	.2519	2.519	20.15	262
263	.2510	2.510	20.07	263
264	.2501	2.50	19.99	264
265	.2492	2.49	19.92	265
266	.2483	2.48	19.84	266
267	.2475	2.47	19.77	267
268	.2466	2.46	19.70	268
269	.2453	2.45	19.63	269
270	.2444	2.44	19.55	270
271	.2435	2.43	19.48	271
272	.8426	2.42	19.41	272
273	.2417	2.41	19.34	273
274	.2408	2.40	19.27	274
275	.2399	2.399	19.20	275
276	.2390	2.390	19.13	276
277	.2381	2.381	19.06	277
278	.2372	2.37	18.99	278
279	.2363	2.36	18.92	279
280	.2357	2.35	18.85	280
281	.2348	2.34	18.78	281
282	.2339	2.339	18.72	282
283	.2331	2.331	18.66	283
284	.2323	2.32	18.59	284
285	.2315	2.31	18.53	285
286	.2307	2.30	18.44	286
287	.2299	2.299	18.38	287
288	.2291	2.291	18.32	288
289	.2283	2.28	18.26	289

Table of Gradients.—*Continued.*

One in	Rise per Chain in feet.	Rise per Furlong in feet.	Rise per Mile in feet.	One in
290	.2275	2.27	18.20	290
291	.2268	2.268	18.14	291
292	.2260	2.260	18.08	292
293	.2252	2.25	18.02	293
294	.2244	2.24	17.96	294
295	.2237	2.23	17.90	295
296	.2229	2.229	17.84	296
297	.2222	2.222	17.78	297
298	.2214	2.21	17.72	298
299	.2207	2.207	17.66	299
300	.22	2.2	17.60	300
301	.2192	2.19	17.54	301
302	.2185	2.18	17.48	302
303	.2178	2.178	17.42	303
304	.2171	2.171	17.36	304
305	.2164	2.16	17.30	305
306	.2157	2.157	17.24	306
307	.2150	2.15	17.19	307
308	.2143	2.14	17.13	308
309	.2136	2.13	17.08	309
310	.2129	2.129	17.03	310
311	.2123	2.12	16.97	311
312	.2116	2.11	16.92	312
313	.2109	2.109	16.87	313
314	.2102	2.10	16.81	314
315	.2095	2.09	16.76	315
316	.2088	2.088	16.71	316
317	.2081	2.08	16.66	317
318	.2074	2.07	16.61	318
319	.2068	2.068	16.56	319
320	.2062	2.06	16.50	320
321	.2055	2.05	16.45	321
322	.2049	2.049	16.39	322
323	.2042	2.04	16.34	323
324	.2036	2.036	16.28	324
325	.2030	2.03	16.22	325
326	.2024	2.04	16.18	326
327	.2018	2.018	16.13	327
328	.2012	2.01	16.09	328
329	.2006	2.006	16.04	329
330	.2	2.	16.	330

EXPLANATION OF TABLES.

The following tables are not intended to be applied in the same way as "Macneill's Tables;" they are for the purpose of shortening the calculations of areas of cross sections, taken at chain stumps. The two cross sections below will at once explain this. Draw *a b* parallel to *c d*, the formation, scale *e f*, *g h*, and

Fig. 1.

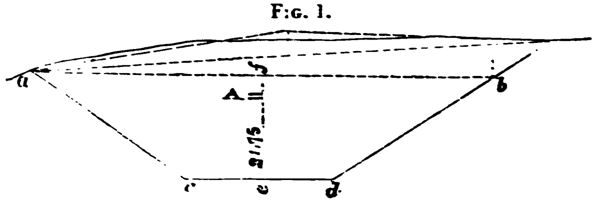
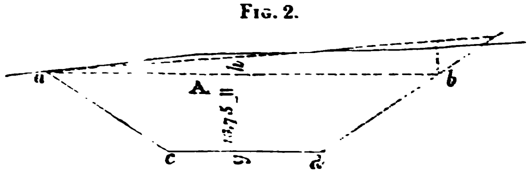


Fig. 2.



at base 30, slopes $1\frac{1}{2}$ to 1; opposite the depths we have the areas of A and A, leaving but the triangle and trapezium to measure by the usual means. The tables are calculated for Base 17, 20, 28, 30, and 31, and for slopes from $\frac{1}{4}$ to 1 to 3 to 1.

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
1.00	17.25	17.50	17.75	18.00	18.50	19.00	19.50	20.00	**1.00**
2.00	35.00	36.00	37.00	38.00	40.00	42.00	44.00	46.00	2.00
3.00	53.25	55.50	57.75	60.00	64.50	69.00	73.50	78.00	3.00
4.00	72.00	76.00	80.00	84.00	94.00	100.00	108.00	116.00	4.00
5.00	91.25	97.50	103.75	110.00	122.50	135.00	147.50	160.00	**5.00**
6.00	111.00	120.00	129.00	138.00	156.00	174.00	192.00	210.00	6.00
7.00	131.25	143.50	155.75	168.00	192.50	217.00	241.50	266.00	7.00
8.00	152.00	168.00	184.00	200.00	232.00	264.00	296.00	328.00	8.00
9.00	173.25	193.50	213.75	234.00	274.50	315.00	355.50	396.00	**9.00**
10.00	195.00	220.00	245.00	270.00	320.00	370.00	420.00	470.00	10.00
11.00	217.25	247.50	277.75	308.00	368.50	429.00	489.90	550.00	11.00
12.00	240.00	276.00	301.00	348.00	420.00	492.00	564.00	636.00	12.00
13.00	263.25	305.50	347.75	390.00	474.50	559.00	643.50	728.00	**13.00**
13.25	269.10	312.96	356.92	400.81	488.59	576.37	664.08	751.93	13.25
13.50	275.06	320.62	366.18	411.74	502.86	593.98	685.10	776.22	13.50
13.75	280.91	328.28	375.55	422.81	517.34	611.87	706.40	800.93	13.75
14.00	287.00	336.00	385.00	434.00	532.00	630.00	788.00	826.00	**14.00**
14.25	293.01	343.78	394.55	445.31	546.84	648.37	749.90	851.43	14.25
14.50	239.06	351.62	404.19	456.75	561.88	667.00	772.12	877.25	14.50
14.75	305.03	359.48	413.85	467.21	576.94	685.87	793.60	903.13	14.75
15.00	311.25	367.50	427.75	480.00	592.50	705.00	817.50	930.00	**15.00**
15.25	317.38	375.51	433.67	491.81	608.09	724.37	840.63	956.93	15.25
15.50	323.56	383.62	443.69	503.75	623.88	744.00	864.12	984.25	15.50
15.75	329.76	391.78	453.80	515.81	639.84	763.87	887.90	1011.93	15.75
16.00	336.00	400.00	464.00	528.00	656.00	784.00	912.00	1040.00	**16.00**
16.25	342.26	408.28	474.30	540.31	672.34	804.37	936.40	1068.43	16.25
16.50	348.56	416.62	484.69	552.75	688.88	825.00	961.12	1097.25	16.50
16.75	354.88	424.91	495.17	565.31	705.59	845.87	986.13	1126.43	16.75
17.00	361.25	433.50	505.75	578.00	722.50	867.00	1011.50	1156.00	**17.00**
17.25	367.63	441.91	516.39	590.77	739.53	888.64	1037.40	1185.81	17.25
17.50	374.00	450.62	527.19	603.75	756.88	910.00	1062.12	1216.25	17.50
17.75	380.51	459.27	538.05	616.81	774.34	931.87	1089.39	1246.93	17.75

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
18.00	387.00	468.00	549.00	630.00	792.00	954.00	1116.00	1278.00	**18.00**
18.25	393.51	470.78	560.04	643.31	809.84	976.37	1142.90	1309.43	18.25
18.50	400.06	485.62	571.19	656.75	827.88	998.00	1170.12	1341.25	18.50
18.75	406.62	494.50	582.37	670.25	846.00	1021.75	1197.50	1373.25	18.75
19.00	413.25	503.50	593.70	684.00	864.50	1045.00	1225.50	1406.00	**19.00**
19.25	419.89	512.53	605.17	697.81	883.09	1068.37	1253.65	1438.93	19.25
19.50	426.56	521.62	616.69	711.75	901.88	1092.00	1281.12	1471.25	19.50
19.75	433.26	530.78	628.30	725.81	920.84	1115.87	1310.90	1505.93	19.75
20.00	440.00	540.00	640.00	740.00	940.00	1140.00	1340.00	1540.00	**20.00**
20.25	446.76	549.28	652.80	754.31	959.34	1164.37	1369.40	1574.43	20.25
20.50	453.56	558.62	663.69	768.75	978.88	1189.00	1398.12	1509.25	20.50
20.75	460.38	568.01	675.67	783.31	998.59	1213.87	1429.13	1644.43	20.75
21.00	467.25	577.50	687.75	798.00	1018.50	1239.00	1459.50	1680.00	**21.00**
21.25	474.14	587.03	699.92	812.81	1038.59	1264.37	1490.15	1715.93	21.25
21.50	480.74	596.62	712.18	827.75	1058.88	1290.00	1521.12	1752.25	21.50
21.75	488.01	606.28	724.22	842.81	1079.29	1315.87	1552.40	1788.93	21.75
22.00	495.00	616.00	737.00	858.00	1100.00	1342.00	1584.00	1826.00	**22.00**
22.25	502.00	625.78	748.52	873.31	1120.79	1368.37	1615.90	1863.43	22.25
22.50	509.00	635.62	762.19	888.75	1141.88	1395.00	1648.12	1901.25	22.50
22.75	516.14	645.53	774.92	904.31	1163.09	1421.87	1680.65	1939.43	22.75
23.00	523.25	655.50	787.75	920.00	1184.50	1449.00	1713.50	1978.00	**23.00**
23.25	530.37	665.50	800.67	935.75	1206.09	1476.37	1746.62	2016.93	23.25
23.50	537.56	675.62	813.69	951.75	1227.88	1503.00	1780.12	2056.25	23.50
23.75	544.76	685.78	826.80	971.81	1249.84	1531.87	1813.90	2095.93	23.75
24.00	552.00	696.00	840.00	984.00	1272.00	1560.00	1848.00	2136.00	**24.00**
24.25	559.26	706.28	853.30	1000.31	1294.34	1588.37	1882.40	2176.43	24.25
24.50	566.56	716.62	866.69	1016.75	1316.88	1617.00	1916.12	2217.25	24.50
24.75	573.89	727.03	879.92	1033.31	1339.00	1645.87	1951.95	2257.43	24.75
25.00	581.25	737.50	893.75	1050.00	1362.50	1675.00	1987.50	2300.00	**25.00**
25.25	588.64	748.03	907.42	1066.31	1385.50	1704.37	2023.05	2341.93	25.25
25.50	596.06	758.62	921.19	1083.75	1408.88	1734.00	2059.12	2383.25	25.50
25.75	603.31	769.28	934.80	1100.81	1431.79	1763.87	2095.40	2426.93	25.75

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
26.00	611.00	780.00	949.00	1118.00	1456.00	1794.00	2132.00	2470.00	**26.00**
26.25	618.51	790.78	963.04	1135.31	1479.84	1824.37	2168 90	2513.43	26.25
26.50	626.06	801.63	977.19	1152.75	1503.87	1855.00	2206.12	2557.25	26.50
26.75	633.44	812.53	991.42	1170.31	1528.09	1885.87	2243.65	2601.43	26.75
27.00	641.25	823.50	1005.75	1188.00	1552.50	1917.00	2281.50	2646.00	**27.00**
27.25	648.89	834.53	1019.67	1205.51	1577.09	1948.37	2319.65	2692.43	27.25
27.50	656.56	845.62	1034.68	1223.75	1601.87	1980.00	2358.12	2736.25	27.50
27.75	664.26	856.78	1049.29	1241.81	1626.84	2011.87	2396.90	2781.93	27·75
28.00	672.00	868.00	1064.00	1264.00	1652.00	2044.00	2436.00	2828.00	**28.00**
28.25	679.76	879.28	1078.79	1278.31	1677.34	2076.37	2475.40	2874.43	28.25
28.50	687.56	890.62	1093.68	1296.75	1702.87	2109.00	2515.12	2921.25	28.50
28.75	695.39	902.03	1108.67	1315.31	1728.59	2141.87	2555.15	2967.43	28 75
29.00	703.25	913.50	1123.75	1334.00	1754.50	2175.00	2595.50	3016.00	**29.00**
29.25	711.14	924.03	1138.92	1352.81	1780.59	2208.37	2636.15	3063.93	29.25
29.50	719.12	936.62	1156.43	1371.75	1806.87	2243.00	2687.12	3112.25	29.50
29.75	727.01	948.28	1169.54	1390.81	1833.34	2275.87	2718.40	3160.93	29.75
30.00	735.00	960.00	1185.00	1410.00	1860.00	2310.00	2760.00	3210.00	**30.00**
30.25	743.01	971.78	1200.55	1429.31	1886.84	2344.37	2801.90	3269.43	30.25
30.50	751.12	983.62	1216.19	1444.50	1913.87	2379.00	2843.12	3309.25	30.50
30.75	759.09	995.53	1231.79	1468.31	1940.84	2413.87	2885.40	3358.93	30.75
31.00	767.25	1007.50	1247.25	1488.00	1968.50	2449.00	2929.50	3410.00	**31.00**
31.25	775.39	1019.53	1263.67	1507.81	1996.09	2484.37	2972.65	3460.93	31.25
31.50	783.56	1031.62	1279.69	1527.75	2023.87	2520.00	3016.12	3512.25	31.50
31.75	791.76	1043.78	1295.80	1547.81	2051.84	2555.87	3059.90	3563.93	31.75
32.00	800.00	1056.00	1312.00	1568.00	2080.00	2592.00	3104.00	3616.00	**32.00**
32.25	808.26	1068.28	1328.30	1588.31	2108.34	2628.37	3148.40	3668.43	32.25
32.50	816.56	1080.62	1344.68	1608.75	2136.87	2665.00	3193.22	3721.25	32.50
32.75	824.89	1093.00	1360.00	1629.31	2165.09	2701.87	3238.15	3774.43	32.75
33.00	833.25	1105.50	1377.65	1650.00	2194.50	2739.00	3283.50	3828.00	**33.00**
33.25	841.64	1118.03	1394.42	1670.81	2223.59	2776.37	3329.15	3881.93	33.25
33.50	850.06	1130.62	1411.19	1691.75	2252.88	2814.00	3375.12	3936.25	33.50
33.75	858.51	1143.28	1428.04	1712.81	2282.34	2851.87	3421.40	3990.93	33.75

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
34.00	867.00	1156.00	1445.00	1734.00	2312.00	2890.00	2890.00	4046.00	**34.00**
34.25	875.51	1168.78	1462.04	1755.31	2341.84	2928.37	2932.65	4101.43	34.25
34.50	883.06	1181.62	1479.18	1776.75	2371.87	2967.00	2975.62	4157.25	34.50
34.75	892.64	1194.53	1496.42	1798.31	2402.09	3005.87	3018.90	4213.43	34.75
35.00	901.25	1207.50	1513.75	1820.00	2432.50	3045.00	3062.50	4270.00	**35.00**
35.25	909.39	1220.53	1531.17	1841.81	2463.09	3084.37	3106.40	4326.93	35.25
35.50	918.56	1234 62	1548.68	1863.75	2493.87	3125.00	3150.62	4386.25	35.50
35.75	926.76	1246.78	1566.29	1885.81	2524.84	3164.87	3196.15	4441.93	35.75
36.00	936.00	1260.00	1584.00	1908.00	2556.00	3204.00	3240.00	4500.00	**36.00**
36.25	944.76	1273.28	1601.79	1930.31	2587.34	3244.37	3285.15	4558.43	36.25
36.50	953.56	1286.62	1619.68	1952.75	2618.87	3284.00	3330.62	4617.25	36.50
36.75	962.39	1300.03	1637.67	1975.31	2650.59	3325.87	3376.40	4676.43	36.75
37.00	971.25	1313.50	1655.75	1998.00	2682.50	3367.00	3422.50	4736.00	**37.00**
37.25	980.18	1327.07	1673.96	2020.81	2714.63	3408.37	3468.90	4795.93	37.25
37.50	989.06	1340.62	1692.18	2043.75	2746.87	3450.00	3515.62	4856.25	37.50
37.75	997.76	1353.78	1710.54	2066.81	2779.34	3491.87	3562.65	4916.93	37.75
38.00	1007.00	1368.00	1729.00	2090.00	2812.00	3534.00	3610.00	4978.00	**38.00**
38.25	1016.01	1381.78	1747.54	2113.31	2844.84	3576.37	3657.65	5039.43	38.25
38.50	1024.56	1395.62	1766.18	2136.75	2877.87	3619.00	3705.62	5101.25	38.50
38.75	1034.14	1409.53	1784.80	2160.31	2910.84	3661.87	3753.65	5162.93	38.75
39.00	1043.25	1423.50	1803.75	2184.00	2944.50	3705.00	3802.50	5226.00	**39.00**
39.25	1052.39	1437.53	1822.42	2207.81	2977.59	3748.37	3851.40	5288.93	39.25
39.50	1061.56	1451.62	1841.69	2231.75	3011.87	3792.00	3900.62	5352.25	39.50
39.75	1070.76	1465.78	1860.78	2255.81	3045.84	3835.87	3950.65	5415.03	39.75
40.00	1080.00	1483.00	1880.00	2280.00	3080.00	3880.00	4000.00	5480.00	**40.00**
40.25	1089.26	1494.28	1889.30	2304.31	3114.34	3924.37	4051.15	5544.43	40.25
40.50	1098.56	1508.62	1918.68	2328.75	3148.87	3968.00	4100.62	5609.25	40.50
40.75	1107.89	1523.03	1938.17	2353.31	3183.59	4013.87	4150.40	5674.43	40.75
41.00	1117.25	1537.50	1957.75	2378.00	3218.50	4059.00	4202.50	5740.00	**41.00**
41.25	1126.64	1552.03	1977.42	2402.81	3253.59	4104.37	4253.90	5805.93	41.25
41.50	1135.06	1566.62	1997.18	2427.75	3288.87	4149.00	4305.62	5872.25	41.50
41.75	1145.51	1581.28	2016.80	2452.81	3324.34	4195.87	4357.15	5938.93	41.75

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
42.00	1155.00	1596.00	2037.00	2478.00	3360.00	4242.00	5124.00	6016.00	**42.00**
42.25	1164.56	1610.75	2057.04	2503.31	3395.74	4288.37	5180.90	6073.43	42.25
42.50	1174.06	1625.62	2077.18	2528.75	3431.87	4335.00	5238.12	6141.25	42.50
42.75	1183.63	1640.52	2097.30	2554.30	3468.07	4381.87	5295.62	6209.40	42.75
43.00	1193.25	1655.62	2117.75	2580.00	3504.50	4429.00	5353.50	6278.00	**43.00**
43.25	1202.89	1670.53	2138.17	2605.81	3541.09	4476.37	5411.65	6346.93	43.25
43.50	1212.56	1685.62	2158.68	2631.75	3577.87	4524.00	5470.12	6416.25	43.50
43.75	1222.26	1700.78	2179.29	2657.81	3614.84	4571.87	5528.90	6485.93	43.75
44.00	1232.00	1716.00	2200.00	2684.00	3652.00	4620.00	5588.00	6556.00	**44.00**
44.25	1241.71	1731.28	2220.79	2710.31	3689.34	4668.37	5647.40	6626.43	44.25
44.50	1251.56	1746.62	2241.68	2736.75	3726.87	4717.00	5707.12	6697.25	44.50
44.75	1261.39	1762.03	2262.67	2763.31	3764.59	4765.87	5767.15	6768.43	44.75
45.00	1271.25	1775.50	2283.75	2790.00	3802.50	4815.00	5827.50	6840.00	**45.00**
45.25	1281.14	1743.03	2304.92	2816.81	3840.59	4864.37	5888.15	6911.93	45.25
45.50	1291.06	1808.62	2326.18	2843.75	3878.87	4914.00	5949.12	6983.25	45.50
45.75	1301.01	1824.28	2347.54	2870.81	3917.34	4963.87	6010.40	7056.93	45.75
46.00	1311.00	1840.00	2369.00	2898.00	3956.00	5014.00	6072.00	7130.00	**46.00**
46.25	1321.01	1855.78	2390.54	2925.31	3994.84	5064.37	6133.90	7203.43	46.25
46.50	1331.06	1871.62	2412.18	2952.75	4033.87	5115.00	6195.12	7277.25	46.50
46.75	1341.14	1887.53	2433.92	2980.31	4073.09	5165.87	6268.65	7351.43	46.75
47.00	1351.25	1903.50	2455.75	3008.00	4112.50	5217.00	6321.50	7426.00	**47.00**
47.25	1361.39	1919.53	2477.67	3035.81	4152.09	5268.37	6384.65	7500.93	47.25
47.50	1371.56	1935.62	2499.68	3063.75	4191.87	5320.00	6448.12	7576.25	47.50
47.75	1381.78	1951.78	2521.79	3091.81	4231.84	5371.87	6511.90	7651.93	47.75
48.00	1392.00	1968.00	2544.00	3120.00	4272.00	5424.00	8576.00	7728.00	**48.00**
48.25	1402.26	1984.28	2566.29	3148.31	4312.34	5476.37	6640.40	7804.43	48.25
48.50	1412.56	2000.62	2588.68	3176.75	4352.87	5529.00	6705.12	7881.25	48.50
48.75	1422.89	2017.03	2611.17	3205.31	4393.59	5581.87	6770.15	7958.43	48.75
49.00	1433.25	2033.50	2633.75	3234.00	4434.50	5635.00	6835.50	8036.00	**49.00**
49.25	1443.64	2054.33	2656.42	3262.81	4475.59	5688.37	6901.15	8113.93	49.25
49.50	1454.06	2066.62	2679.18	3291.75	4516.87	5742.00	6967.12	8192.25	49.50
49.75	1464.51	2083.28	2702.05	3320.81	4558.34	5795.87	7033.40	8270.93	49.75

BASE 17.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
50.00	1475.00	2100.00	2725.00	3350.00	4600.00	5850.00	7100.00	8350.00	**50.00**
50.25	1485.51	2116.78	2748.04	3379.31	4641.84	5904.37	7166.90	8429.43	50.25
50.50	1496.06	2133.62	2770.87	3408.75	4683.87	5959.00	7234.12	8509.25	50.50
50.75	1506.64	2150.53	2794.42	3438.31	4726.09	6013.87	7301.65	8589.43	50.75
51.00	1517.25	2167.50	2817.75	3468.00	4768.50	6069.00	7369.50	8670.00	**51.00**
51.25	1527.89	2184.53	2841.17	3497.81	4811.09	6124.37	7437.65	8750.93	51.25
51.50	1538.56	2201.62	2864.68	3527.75	4853.87	6179.00	7506.12	8832.25	51.50
51.75	1548.76	2218.78	2887.79	3557.81	4896.84	6235.87	7574.90	8913.93	51.75
52.00	1560.00	2236.00	2912.00	3588.00	4940.00	6292.00	7644.00	8996.00	**52.00**
52.25	1570.76	2253.28	2935.79	3618.31	4983.34	6348.37	7713.40	9078.43	52.25
52.50	1581.56	2270.62	2959.68	3648.75	5026.87	6405.00	7783.12	9161.25	52.50
52.75	1592.39	2288.03	2983.77	3689.31	5070.59	6461.87	7853.15	9244.43	52.75
53.00	1603.25	2305.50	3007.75	3710.00	5114.50	6519.00	7893.50	9328.00	**53.00**
53.25	1614.14	2323.03	3031.92	3740.81	5158.59	6576.37	7994.15	9411.93	53.25
53.50	1625.06	2340.62	3056.18	3771.75	5202.87	6633.00	8065.12	9496.25	53.50
53.75	1636.01	2358.28	3080.54	3802.81	5247.34	6691.87	8136.37	9580.93	53.75
54.00	1647.00	2376.00	3105.00	3834.00	5292.00	6750.00	8208.00	9666.00	**54.00**
54.25	1658.01	2393.78	3129.54	3865.31	5336.84	6808.37	8279.90	9751.43	54.25
54.50	1669.06	2411.62	3153.18	3896.75	5381.87	6867.00	8352.12	9837.25	54.50
54.75	1680.64	2429.53	3179.42	3928.31	5427.09	6925.87	8424.65	9923.43	54.75
55.00	1691.25	2447.50	3203.75	3960.00	5472.50	6985.00	8497.50	10010.00	**55.00**
55.25	1702.39	2465.53	3228.67	3991.81	5518.09	7044.37	8570.65	10096.93	55.25
55.50	1713.56	2483.62	3253.68	4023.75	5563.87	7104.00	8644.12	10184.25	55.50
55.75	1724.76	2501.78	3278.79	4055.81	5609.84	7163.87	8718.90	10271.93	55.75
56.00	1736.00	2520.00	3304.00	4088.00	5656.00	7224.00	8792.00	10360.00	**56.00**
56.25	1747.26	2538.28	3329.29	4120.31	5702.34	7284.37	8866.40	10448.43	56.25
56.50	1758.56	2556.62	3354.68	4152.75	5748.87	7345.00	8941.12	10537.25	56.50
56.75	1769.89	2575.03	3380.17	4185.21	5795.59	7405.87	9016.15	10625.43	56.75
57.00	1780.25	2592.50	3405.75	4217.00	5841.50	7466.00	9090.50	10715.00	**57.00**
57.25	1791.64	2611.03	3430.42	4249.81	5888.59	7527.37	9166.15	10804.93	57.25
57.50	1803.06	2629.62	3456.18	4282.75	5935.87	7589.00	9242.12	10895.25	57.50
57.75	1814.51	2648.28	3482.04	4315.81	5983.34	7650.87	9318.40	10985.93	57.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
1.00	20.25	20.50	20.75	21.00	21.50	22.00	22.50	23.00	**1.00**
2.00	41.00	42.00	43.00	44.00	46.00	48.00	50.00	52.00	2.00
3.00	62.25	64.50	66.75	69.00	73.50	78.00	82.50	87.00	3.00
4.00	84.00	88.00	92.00	96.00	104.00	112.00	120.00	128.00	4.00
5.00	106.25	112.50	118.75	125.00	137.50	150.00	162.50	175.00	**5.00**
6.00	129.00	138.00	147.00	156.00	174.00	192.00	210.00	228.00	6.00
7.00	152.25	164.50	176.75	189.00	213.50	238.00	262.50	287.00	7.00
8.00	166.00	192.00	208.00	224.00	256.00	288.00	320.00	352.00	8.00
9.00	200.25	220.50	240.75	261.00	301.50	342.00	382.50	423.00	**9.00**
10.00	225.00	250.00	275.00	300.00	350.00	400.00	450.00	500.00	10.00
11.00	250.25	280.50	310.75	341.00	401.50	462.00	522.00	583.00	11.00
12.00	276.00	312.00	343.00	384.00	456.00	528.00	600.00	672.00	12.00
13.00	302.25	344.50	386.75	429.00	513.50	598.00	682.50	767.00	**13.00**
13.25	308.85	352.71	396.67	440.56	528.34	616.12	703.83	791.68	13.25
13.50	315.56	361.12	406.68	452.24	543.36	634.48	725.60	816.72	13.50
13.75	322.26	369.53	416.80	464.06	558.59	653.12	747.65	842.18	13.75
14.00	329.00	378.00	427.00	476.00	574.00	672.00	770.00	868.00	**14.00**
14.25	335.76	386.53	437.30	488.06	589.59	691.12	792.65	894 18	14.25
14.50	342.66	395.12	447.69	500.25	605.38	710.50	815.62	920.75	14.50
14.75	349.28	403.73	458.10	512.46	621.19	730.12	838.85	947.38	14.75
15.00	356.25	412.50	468.75	525.00	637.50	750.00	862.50	975.00	**15.00**
15.25	363.13	421.26	479.42	537.56	653.84	770.12	886.38	1002.68	15.25
15.50	370.06	430.12	490.10	550.25	670.38	790.50	910.62	1030.75	15.50
15.75	377.01	439.03	501.05	563.07	687.09	811.12	935.15	1059.18	15.75
16.00	384.00	448.00	512 00	576.00	704.00	832.00	960.00	1088.00	**16.00**
16.25	391.01	457.03	523.05	589.06	721.09	853.12	985.15	1117.18	16.25
16.50	396.06	466.12	534.19	602.25	738.38	874.50	1010.62	1146.75	16.50
16.75	405.13	475.26	545.42	615.56	755.84	896.12	1036.38	1176.68	16.75
17.00	412.25	484.50	556.75	629.00	773.50	918.00	1060.50	1207.00	**17.00**
17.25	419.38	493.76	568.14	642.52	791.28	940.39	1089.15	1237.56	17.25
17.50	426.50	503.12	579.69	656.25	809.38	962.50	1115.62	1268.75	17.50
17.75	432.76	512.52	591.30	670.06	827.59	985.12	1142.64	1300.18	17.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
18.00	441.00	522.00	603.00	684.00	846.00	1008.00	1170.00	1332.00	**18.00**
18.25	448.26	531.53	614.79	698.06	864.59	1031.12	1197.65	1364.18	18.25
18.50	455.56	541.12	626.69	712.25	883.38	1054.50	1225.62	1396.75	18.50
18.75	462.87	550.75	638.50	726.50	902.25	1078.00	1253.75	1429.50	18.75
19.00	470.25	560.50	650.70	741.00	921.00	1102.00	1282.50	1463.00	**19.00**
19.25	477.64	570.28	662.92	756.56	940.84	1126.12	1311.40	1496.68	19.25
19.50	485.06	580.12	675.19	770.25	960.38	1150.50	1340.62	1530.75	19.50
19.75	492.56	590.03	687.55	785.06	980.09	1175.12	1370.15	1565.18	19.75
20.00	500.00	600.00	700.00	800.00	1000.00	1200.00	1400 00	1600.00	**20.00**
20.25	507.51	610.03	712.55	815.06	1020.09	1225.12	1430.15	1635.18	20.25
20.50	515.06	620.12	725.19	830.25	1040.38	1250.50	1460.62	1670.75	20.50
20.75	522.63	630.26	737.92	845.56	1060.84	1276.12	1491.38	1706.68	20.75
21.00	530.25	640.50	750.75	861.00	1081.50	1302.00	1522.50	1743.00	**21.00**
21.25	537.89	650.78	763.67	876.56	1102.34	1328.12	1553.90	1779.68	21.25
21.50	545.24	661.12	776.68	892.25	1123.38	1354.50	1585.62	1816.75	21.50
21.75	553.10	671.53	789.27	908.06	1144.54	1381.12	1617.65	1854.18	21.75
22.00	561.00	682.00	803.00	924.00	1166.00	1408.00	1650.00	1892.00	**22.00**
22.25	568.76	692.53	815.27	940.06	1187.54	1435.12	1682.65	1930.18	22.25
22.50	576 50	703.12	829.69	956 25	1219.38	1462.50	1715.62	1968.75	22.50
22.75	584.30	713.73	843.17	972.56	1231.34	1490.12	1748.90	2007.68	22.75
23.00	592.25	724.50	856.75	989.00	1253.50	1518.00	1782.50	2047.00	**23.00**
23.25	600.12	735.25	870.42	1005.56	1275.84	1546.12	1816.37	2086.68	23.25
23.50	608.00	746.12	884.19	1022.25	1298.38	1574.50	1850.62	2126.75	23.50
23.75	615.89	757.03	898.05	1039.06	1321.09	1603.12	1885.15	2167.18	23.75
24.00	624.00	768.00	912.00	1056.00	1344.00	1632.00	1920.00	2208.00	**24.00**
24.25	632.01	779.03	926.03	1073.06	1367.09	1661.12	1955.15	2249.18	24.25
24.50	640.06	790.12	940.19	1090.25	1390.38	1690.50	1990.62	2290.75	24.50
24.75	648.14	801.28	954.17	1107.56	1413.34	1720.12	2026.20	2331.68	24.75
25.00	656.25	812.50	968.75	1125.00	1437.50	1750.00	2062.50	2375.00	**25.00**
25.25	664.39	823.78	983.17	1142.56	1461.34	1780.12	2098.80	2417.68	25.25
25.50	672.56	835.12	997.69	1160.25	1485.38	1810.50	2135.62	2460.75	25.50
25.75	680.76	846.53	1012.05	1178.06	1509.09	1841.12	2172.65	2504.18	25.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
26.00	689.00	858.00	1027.00	1196.00	1534.00	1872.00	2210.00	2548.00	**26.00**
26.25	697.27	869.53	1041.70	1214.06	1558.59	1903.12	2247.65	2592.18	26.25
26.50	705.56	881.13	1056.59	1232.25	1583.37	1934.50	2285.62	2636.75	26.50
26.75	713.89	892.78	1071.67	1250.56	1608.34	1966.12	2323.90	2681.68	26.75
27.00	722.25	904.50	1086.75	1269.00	1633.50	1998.00	2362.50	2727.00	**27.00**
27.25	730.64	916.28	1101.42	1287.56	1658.84	2030.12	2401.40	2774.18	27.25
27.50	739.06	928.12	1117.18	1306.25	1684.37	2062.50	2440.62	2818.75	27.50
27.75	747.51	940.03	1132.54	1325.06	1710.09	2095.12	2480.15	2865.18	27.75
28.00	756.00	952.00	1148.00	1344.00	1736.00	2128.00	2520.00	2912.00	**28.00**
28.25	764.51	964.03	1163.54	1363.06	1762.09	2161.12	2560.15	2959.18	28.25
28.50	773.06	976.12	1179.18	1382.25	1788.37	2194.50	2600.62	3006.75	28.50
28.75	781.64	988.28	1194.92	1401.56	1814.84	2228.12	2641.40	3054.68	28.75
29.00	790.25	1000.50	1210.75	1421.00	1841.50	2262.00	2682.50	3103.00	**29.00**
29.25	798.89	1012.78	1226.67	1440.56	1868.34	2296.12	2723.90	3151.68	29.25
29.50	807.56	1025.12	1244.93	1460.25	1895.37	2330.50	2765.62	3200.75	29.50
29.75	816.26	1037.53	1258.79	1480.06	1922.59	2365.12	2807.65	3250.18	29.75
30.00	825.00	1050.00	1275.00	1500.00	1950.00	2400.00	2850.00	3300.00	**30.00**
30.25	833.76	1062.53	1291.30	1520.06	1977.59	2435.12	2892.65	3350.18	30.25
30.50	842.56	1075.12	1307.69	1540.25	2005.37	2470.50	2935.62	3400.75	30.50
30.75	851.39	1087.78	1324.04	1560.56	2033.09	2506.12	2978.65	3451.18	30.75
31.00	860.25	1100.50	1340.25	1581.00	2061.50	2542.00	3022.50	3503.00	**31.00**
31.25	869.14	1113.28	1357.42	1601.56	2089.84	2578.12	3066.40	3554.68	31.25
31.50	878.06	1126.12	1374.19	1622.25	2118.37	2614.50	3110.62	3606.75	31.50
31.75	887.01	1139.03	1391.05	1643.06	2147.09	2651.12	3155.15	3669.18	31.75
32.00	896.00	1152.00	1408.00	1664.00	2176.00	2688.00	3200.00	3712.00	**32.00**
32.25	905.01	1165.03	1425.05	1685.06	2205.09	2725.12	3245.15	3765.18	32.25
32.50	914.06	1178.12	1442.18	1706.25	2234.37	2762.50	3290.62	3818.75	32.50
32.75	923.14	1191.28	1459.17	1727.56	2263.34	2800.12	3336.40	3872.68	32.75
33.00	932.25	1204.50	1476.75	1749.00	2293.50	2838.00	3382.50	3927.00	**33.00**
33.25	941.39	1217.78	1494.17	1770.56	2323.34	2876.12	3428.90	3981.68	33.25
33.50	950.56	1231.12	1511.69	1792.25	2353.38	2914.50	3475.62	4036.75	33.50
33.75	959.76	1244.53	1529.29	1797.06	2383.59	2953.12	3522.65	4092.18	33.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
34.00	969.00	1258.00	1547.00	1836.00	2414.00	2992.00	3570.00	4148.00	**34.00**
34.25	978.26	1271.53	1564.79	1858.06	2444.59	3031.12	3617.65	4204.18	34.25
34.50	987.56	1285.12	1582.68	1880.25	2475.37	3070.50	3665.62	4260.75	34.50
34.75	996.89	1298.78	1600.67	1902.56	2506.34	3110.12	3713.90	4317.68	34.75
35.00	1006.25	1312.50	1618.75	1925.00	2537.50	3150.00	3762.50	4375.00	**35.00**
35.25	1015.14	1326.28	1636.92	1947.56	2568.84	3190.12	3811.40	4432.68	35.25
35.50	1025.06	1340.12	1645.18	1970.25	2600.37	3230.50	3860.62	4490.75	35.50
35.75	1034.01	1354.03	1673.54	1993.06	2632.09	3271.12	3910.15	4549.18	35.75
36.00	1044.00	1368.00	1692.00	2016.00	2664.00	3312.00	3960.00	4608.00	**36.00**
36.25	1053.51	1382.03	1710.54	2039.06	2696.09	3353.12	4010.50	4667.18	36.25
36.50	1063.06	1396.12	1729.18	2062.25	2728.37	3394.50	4060.62	4726.75	36.50
36.75	1072.64	1410.28	1747.92	2085.56	2760.84	3436.12	4111.40	4786.68	36.75
37.00	1082.25	1424.50	1766.75	2109.00	2793.50	3478.00	4162.50	4847.00	**37.00**
37.25	1091.89	1438.78	1785.67	2132.56	2826.34	3520.12	4213.90	4907.68	37.25
37.50	1101.56	1453.12	1804.68	2156.25	2859.37	3562.50	4265.62	4968.75	37.50
37.75	1111.01	1467.03	1823.79	2180.06	2892.59	3605.12	4317.65	5030.18	37.75
38.00	1121.00	1482.00	1843.00	2204.00	2926.00	3648.00	4370.00	5092.00	**38.00**
38.25	1130.76	1496.53	1862.29	2228.06	2959.59	3691.12	4422.65	5154.18	38.25
38.50	1140.06	1511.12	1881.68	2252.25	2993.37	3734.50	4475.62	5216.75	38.50
38.75	1150.39	1525.78	1901.05	2276.56	3027.09	3778.12	4529.00	5279.18	38.75
39.00	1160.25	1540.50	1920.75	2301.00	3061.50	3822.00	4582.50	5343.00	**39.00**
39.25	1170.14	1555.28	1940.17	2325.56	3095.34	3866.12	4636.40	5406.68	39.25
39.50	1180.06	1570.12	1960.19	2350.25	3130.37	3910.50	4690.62	5470.75	39.50
39.75	1190.01	1585.03	1980.03	2375.06	3165.09	3955.12	4745.15	5535.18	39.75
40.00	1200.25	1600.00	2000.00	2400.00	3200.00	4000.00	4800.00	5600.00	**40.00**
40.25	1215.01	1615.03	2020.05	2425.06	3235.09	4045.12	4855.15	5665.18	40.25
40.50	1220.06	1630.12	2040.18	2450.25	3270.37	4090.50	4910.62	5730.75	40.50
40.75	1230.14	1645.28	2050.42	2475.56	3305.84	4136.12	4966.40	5796.68	40.75
41.00	1240.25	1660.50	2080.75	2501.00	3341.50	4182.00	5022.50	5863.00	**41.00**
41.25	1250.39	1675.78	2101.17	2526.56	3377.34	4228.12	5078.90	5929.68	41.25
41.50	1260.56	1691.12	2121.68	2552.25	3413.37	4274.50	5135.62	5996.75	41.50
41.75	1270.76	1706.53	2142.05	2578.06	3449.59	4321.12	5192.65	6054.18	41.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
42.00	1281.00	1722.00	2163.00	2604.00	3486.00	4368.00	5250.00	6132.00	**42.00**
42.25	1291.26	1737.53	2183.79	2630.06	3522.59	4415.12	5307.65	6200.18	42.25
42.50	1301.56	1753.12	2204.68	2656.25	3559.37	4462.50	5365.62	6268.75	42.50
42.75	1311.88	1768.77	2225.65	2682.55	3596.32	4510.10	5423.87	6377.65	42.75
43.00	1322.25	1784.50	2246.75	2709.00	3633.50	4558.00	5482.50	6407.00	**43.00**
43.25	1332.64	1800.28	2267.92	2735.56	3670.84	4606.12	5541.40	6476.68	43.25
43.50	1343.06	1816.12	2289.18	2762.25	3708.37	4654.50	5600.62	6546.75	43.50
43.75	1353.51	1832.03	2310.54	2789.06	3746.09	4703.12	5660.15	6617.18	43.75
44.00	1364.00	1848.00	2332.00	2816.00	3784.00	4752.00	5720.00	6688.00	**44.00**
44.25	1374.61	1864.03	2353.54	2843.06	3822.09	4801.12	5780.15	6759.18	44.25
44.50	1385.06	1880.12	2375.18	2870.25	3860.37	4850.50	5840.62	6830.75	44.50
44.75	1395.64	1896.28	2396.92	2897.56	3898.84	4900.12	5901.40	6902.68	44.75
45.00	1406.25	1912.50	2418.75	2925.00	3937.50	4950.00	5962.50	6975.00	**45.00**
45.25	1416.89	1928.78	2440.67	2952.56	3976.34	5000.12	6023.90	7047.68	45.25
45.50	1427.56	1945.12	2462.68	2980.25	4015.37	5050.50	6085.62	7120.75	45.50
45.75	1438.20	1961.53	2484.79	3008.06	4054.59	5101.12	6147.65	7194.18	45.75
46.00	1449.00	1978.00	2507.00	3036.00	4094.00	5152.00	6210.56	7268.00	**46.00**
46.25	1459.75	1994.53	2529.29	3064.06	4133.59	5203.12	6272.65	7342.18	46.25
46.50	1470.56	2011.12	2551.68	3092.25	4173.37	5254.50	6335.62	7416.75	46.50
46.75	1481.39	2027.78	2574.17	3120.56	4213.34	5306.12	6398.90	7491.68	46.75
47.00	1492.25	2044.50	2596.75	3149.00	4253.50	5358.00	6462.50	7567.00	**47.00**
47.25	1503.14	2061.28	2619.42	3177.56	4293.84	5410.12	6526.40	7642.68	47.25
47.50	1514.06	2078.12	2642.18	3206.25	4334.37	5462.50	6590.62	7718.75	47.50
47.75	1525.01	2095.03	2665.04	3235.06	4375.09	5515.12	6655.15	7795.18	47.75
48.00	1536.00	2112.00	2688.00	3264.00	4416.00	5568.00	6720.00	7872.00	**48.00**
48.25	1547.01	2129.03	2711.04	3293.06	4457.09	5621.12	6785.15	7949.18	48.25
48.50	1558.06	2146.12	2734.18	3322.23	4498.37	5674.50	6850.62	8026.75	48.50
48.75	1569.14	2163.28	2757.42	3351.56	4539.84	5728.12	6916.45	8104.68	48.75
49.00	1580.25	2180.50	2780.75	3381.00	4581.50	5782.00	6982.50	8183.00	**49.00**
49.25	1591.39	2197.78	2804.17	3410.56	4623.34	5836.12	7048.90	8261.68	49.25
49.50	1602.56	2215.12	2827.68	3440.25	4665.37	5890.50	7115.62	8340.75	49.50
49.75	1613.76	2232.53	2851.29	3470.06	4707.59	5945.12	7182.65	8420.18	49.75

BASE 20.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
50.00	1625.00	2250.00	2875.00	3500.00	4750.00	6000.00	7250.00	8500.00	**50.00**
50.25	1636.26	2267.53	2898.79	3530.06	4792.59	6055.12	7317.65	8580.18	50.25
50.50	1647.56	2285.12	2922.68	3562.25	4835.37	6110.56	7385.62	8660.75	50.50
50.75	1658.89	2302.78	2946.67	3590.56	4878.34	6166.12	7453.90	8741.68	50.75
51.00	1670.25	2320.50	2970.00	3621.00	4921.50	6222.00	7522.50	8823.00	**51.00**
51.25	1681.64	2338.28	2994.92	3651.56	4964.84	6278.12	7591.40	8904.68	51.25
51.50	1693.06	2356.12	3019.18	3682.25	5008.37	6334.50	7660.62	8986.75	51.50
51.75	1704.51	2374.03	3043.04	3713.06	5052.09	6391.12	7730.15	9069.18	51.75
52.00	1716.00	2392.00	3068.00	3744.00	5096.00	6448.00	7800.00	9152.00	**52.00**
52.25	1727.51	2410.03	3092.54	3775.06	5140.09	6505.12	7870.15	9235.18	52.25
52.50	1739.06	2428.12	3117.18	3806.25	5184.37	6562.50	7940.62	9318.75	52.50
52.75	1750.64	2446.28	3141.92	3837.56	5228.84	6615.12	8011.40	9402.68	52.75
53.00	1762.25	2464.50	3166.75	3869.00	5273.50	6678.00	8082.50	9487.00	**53.00**
53.25	1773.89	2482.78	3191.67	3900.56	5318.34	6736.12	8153.90	9571.68	53.25
53.50	1785.56	2501.12	3216.68	3932.25	5363.37	6794.50	8225.62	9676.75	53.50
53.75	1797.26	2519.53	3241.79	3964.06	5408.59	6853.12	8297.65	9742.18	53.75
54.00	1809.00	2538.00	3267.00	3996.00	5454.00	6912.00	8370.00	9828.00	**54.00**
54.25	1820.76	2556.53	3292.29	4028.06	5499.59	6971.12	8442.65	9914.18	54.25
54.50	1832.56	2575.12	3317.68	4062.25	5545.37	7030.50	8515.62	10000.75	54.50
54.75	1844.39	2593.78	3343.67	4092.56	5591.34	7090.12	8588.90	10087.68	54.75
55.00	1856.25	2612.50	3368.75	4125.00	5637.50	7150.00	8662.50	10175.00	**55.00**
55.25	1868.14	2631.28	3394.42	4157.56	5683.84	7210.12	8736.40	10262.68	55.25
55.50	1880.06	2650.12	3420.18	4190.25	5730.37	7270.50	8810.62	10350.75	55.50
55.75	1892.01	2669.03	3446.04	4223.06	5777.09	7331.12	8886.15	10439.18	55.75
56.00	1904.00	2688.00	3472.00	4256.00	5824.00	7392.00	8960.00	10528.00	**56.00**
56.25	1916.01	2707.03	3498.04	4289.06	5871.09	7453.12	9035.15	10617.18	56.25
56.50	1928.06	2726.12	3524.18	4322.25	5918.37	7514.50	9110.62	10706.75	56.50
56.75	1940.14	2745.28	3550.42	4355.56	5965.84	7576.12	9186.40	10795.68	56.75
57.00	1952.25	2764.50	3576.75	4389.00	6013.50	7638.00	9262.50	10887.00	**57.00**
57.25	1964.39	2783.78	3603.17	4422.56	6061.34	7700.12	9338.90	10977.68	57.25
57.50	1976.56	2803.12	3629.68	4456.25	6109.37	7762.50	9415.62	11068.75	57.50
57.75	1988.76	2822.53	3656.29	4490.06	6157.59	7825.12	9492.65	11160.18	57.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1	2 to 1.	2½ to 1.	3 to 1.	Depths.
1.00	28.25	28.50	28.75	29.00	29.50	30.00	30.50	31.00	**1.00**
2.00	57.00	58.00	59.00	60.00	62.00	64.00	66.00	68.00	2.00
3.00	86.25	88.50	90.75	93.00	97.50	102.00	106.50	111.00	3.00
4.00	116.00	120.00	124.00	128.00	136.00	144.00	152.00	160.00	4.00
5.00	146.25	152.50	158.75	165.00	177.50	190.00	202.50	215.00	**5.00**
6.00	177.00	186.00	195.00	204.00	222.00	242.00	258.00	276.00	6.00
7.00	208.25	220.50	232.75	245.00	269.50	294.00	318.50	343.00	7.00
8.00	240.00	256.00	272.00	288.00	320.00	352.00	374.00	416.00	8.00
9.00	272.25	292.50	312.75	333.00	373.50	414.00	454.50	495.00	**9.00**
10.00	305.00	330.00	355.00	380.00	430.00	480.00	530.00	580.00	10.00
11.00	338.25	368.50	398.75	429.00	489.50	550.00	610.50	671.00	11.00
12.00	372.00	408.00	439.00	480.00	552.00	624.00	696.00	768.00	12.00
13.00	406.25	448.50	490.75	533.00	627.50	702.00	786.50	871.00	**13.00**
13.25	414.85	458.71	502.67	546.56	634.34	722.12	809.83	897.68	13.25
13.50	423.56	469.12	514.68	560.24	651.36	742.48	833.60	924.72	13.50
13.75	432.26	479.53	526.80	574.06	668.59	763.12	857.65	952.18	13.75
14.00	441.00	490.00	539.00	588.00	686.00	784.00	882.00	980.00	**14.00**
14.25	449.76	500.53	551.30	602.06	703.59	805.12	906.65	1008.18	14.25
14.50	458.56	511.12	563.69	616.25	721.38	826.00	931.62	1036.73	14.50
14.75	467.28	521.73	576.10	630.46	739.19	848.12	956.85	1065.38	14.75
15.00	476.25	532.50	588.75	645.00	757.50	870.00	982.50	1095.00	**15.00**
15.25	485.13	543.26	601.42	659.56	775.84	892.12	1008.38	1124.68	15.25
15.50	494.06	554.12	614.19	674.25	794.38	914.50	1034.62	1154.75	15.50
15.75	503.01	565.03	627.05	689.06	813.09	937.12	1061.15	1185.18	15.75
16.00	512.00	576.00	640.00	704.00	832.00	960.00	1088.00	1216.00	**16.00**
16.25	521.01	587.03	653.05	719.06	851.09	983.12	1115.15	1247.18	16.25
16.50	530.06	598.12	666.19	734.25	870.38	1006.50	1142.62	1278.75	16.50
16.75	539.13	609.26	679.42	749.56	889.84	1030.12	1170.38	1310.68	16.75
17.00	548.25	620.50	692.75	765.00	909.50	1054.00	1198.50	1343.00	**17.00**
17.25	557.38	631.76	706.14	780.52	929.28	1078.39	1227.15	1375.56	17.25
17.50	566.50	643.12	719.69	796.25	949.38	1102.00	1255.62	1408.75	17.50
17.75	575.76	654.52	733.30	812.06	969.59	1127.12	1284.64	1442.18	17.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
18.00	585.00	666.00	747.00	828.00	990.00	1152.00	1314.00	1476.00	**18.00**
18.25	594.26	677.53	760.79	844.06	1010.59	1177.12	1343.65	1510.18	18.25
18.50	603.56	689.12	774.69	860.25	1031.38	1202.50	1373.62	1544.75	18.50
18.75	612.87	700.75	788.62	876.50	1052.25	1228.00	1403.75	1579.50	18.75
19.00	622.25	712.50	802.70	893.00	1073.50	1254.00	1434.50	1615.00	**19.00**
19.25	631.64	724.28	816.92	909.56	1094.84	1280.12	1465.40	1650.68	19.25
19.50	641.06	736.12	831.19	926.25	1116.38	1306.50	1496.62	1686.75	19.50
19.75	650.51	748.03	845.55	943.06	1138.09	1333.12	1528.15	1723.18	19.75
20.00	660.00	760.00	860.00	960.00	1160.00	1360.00	1560.00	1760.00	**20.00**
20.25	669.51	772.03	874.55	977.06	1182.09	1387.12	1592.15	1797.18	20.25
20.50	679.06	784.12	889.19	994.25	1204.38	1414.50	1624.62	1834.77	20.50
20.75	688.63	796.26	903.92	1011.56	1226.84	1442.12	1657.38	1872.68	20.75
21.00	698.25	808.50	918.75	1029.00	1249.50	1470.00	1690.50	1911.00	**21.00**
21.25	707.89	820.78	933.67	1046.56	1272.34	1498.12	1723.90	1949.68	21.25
21.50	717.24	833.12	948.68	1064.25	1295.38	1526.50	1757.62	1988.75	21.50
21.75	727.10	845.53	963.27	1082.06	1318.54	1555.12	1791.65	2028.18	21.75
22.00	737.00	858.00	979.00	1100.00	1342.00	1584.00	1826.00	2068.00	**22.00**
22.25	746.76	870.53	993.27	1118.06	1365.54	1613.12	1860.65	2108.18	22.25
22.50	756.50	883.12	1009.69	1136.25	1389.38	1642.50	1895.62	2148.75	22.50
22.75	766.39	895.78	1025.17	1154.56	1413.34	1672.12	1930.90	2189.68	22.75
23.00	776.25	908.50	1040.75	1173.00	1437.50	1702.00	1966.50	2231.00	**23.00**
23.25	786.12	921.25	1056.42	1191.56	1461.84	1732.12	2002.37	2272.68	23.25
23.50	796.06	934.12	1063.19	1210.25	1486.38	1762.50	2038.62	2314.75	23.50
23.75	805.89	947.03	1088.05	1229.06	1511.09	1793.12	2075.15	2357.18	23.75
24.00	816.00	960.00	1104.00	1248.00	1536.00	1824.00	2112.00	2400.00	**24.00**
24.25	826.01	973.03	1120.05	1267.06	1561.09	1855.12	2149.15	2443.18	24.25
24.50	836.06	986.12	1136.19	1286.25	1586.38	1886.50	2186.62	2486.75	24.50
24.75	846.14	999.28	1152.17	1305.56	1611.34	1918.12	2224.20	2529.68	24.75
25.00	856.25	1012.50	1168.75	1325.00	1637.50	1950.00	2262.50	2575.00	**25.00**
25.25	866.39	1025.78	1185.17	1344.56	1663.34	1982.12	2300.80	2619.68	25.25
25.50	876.56	1039.12	1201.69	1364.25	1689.38	2014.50	2339.62	2664.75	25.50
25.75	886.76	1052.53	1218.05	1384.06	1715.09	2047.12	2378.65	2710.18	25.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1	3 to 1.	Depths.
26.00	897.00	1066.00	1235.00	1404.00	1742.00	2080.00	2418.00	2756.00	**26.00**
26.25	907.25	1079.53	1251.79	1424.06	1768.59	2113.12	2457.65	2802.18	26.25
26.50	917.56	1093.13	1268.69	1444.25	1795.37	2146.56	2497.62	2848.75	26.50
26.75	927.89	1106.78	1285.67	1464.56	1822.34	2180.12	2537.90	2895.68	26.75
27.00	938.25	1120.50	1302.75	1485.00	1849.50	2214.00	2578.50	2943.00	**27.00**
27.25	948.64	1134.28	1319.42	1505.56	1876.84	2248.12	2619.40	2992.18	27.25
27.50	959.06	1148.12	1337.18	1526.25	1904.37	2282.50	2660.62	3038.75	27.50
27.75	969.51	1162.03	1354.54	1547.06	1932.09	2317.12	2702.15	3087.18	27.75
28.00	980.00	1176.00	1372.00	1568.00	1960.00	2352.00	2744.00	3136.00	**28.00**
28.25	990.51	1190.03	1389.54	1589.06	1988.09	2387.12	2786.15	3185.18	28.25
28.50	1001.06	1204.12	1407.18	1610.25	2016.37	2422.50	2828.62	3234.75	28.50
28.75	1011.64	1218.28	1424.92	1631.56	2044.84	2458.12	2871.40	3284.68	28.75
29.00	1022.25	1232.50	1442.75	1653.00	2073.50	2494.00	2914.50	3335.00	**29.00**
29.25	1032.89	1246.78	1460.67	1674.56	2102.34	2530.12	2957.90	3385.68	29.25
29.50	1043.56	1261.12	1480.93	1696.25	2131.37	2566.50	3001.62	3436.75	29.50
29.75	1054.26	1275.53	1496.79	1718.06	2160.59	2603.12	3045.65	3488.18	29.75
30.00	1065.00	1290.00	1515.00	1740.00	2190.00	2640.00	3090.00	3540.00	**30.00**
30.25	1075.76	1304.53	1533.30	1762.06	2219.59	2677.12	3134.65	3592.18	30.25
30.50	1086.50	1319.12	1551.69	1784.25	2249.37	2714.50	3179.62	3644.75	30.50
30.75	1097.39	1333.78	1570.04	1806.56	2279.09	2752.12	3224.65	3697.18	30.75
31.00	1108.25	1348.50	1588.25	1829.00	2309.50	2790.00	3270.50	3751.00	**31.00**
31.25	1119.14	1363.28	1607.42	1851.56	2339.84	2828.12	3316.40	3804.68	31.25
31.50	1130.06	1378.12	1626.19	1874.25	2370.37	2866.50	3362.62	3858.75	31.50
31.75	1141.01	1393.03	1645.05	1897.06	2401.09	2905.12	3409.19	3913.18	31.75
32.00	1152.00	1408.00	1664.00	1916.00	2432.00	2944.00	3456.00	3968.00	**32.00**
32.25	1163.01	1423.03	1683.05	1943.06	2463.09	2983.12	3503.15	4023.18	32.25
32.50	1174.06	1438.12	1702.18	1966.25	2494.37	3022.50	3550.62	4078.75	32.50
32.75	1185.14	1453.28	1721.17	1989.56	2525.34	3062.12	3598.40	4134.68	32.75
33.00	1196.25	1468.50	1740.75	2013.00	2557.50	3102.00	3646.40	4191.00	**33.00**
33.25	1207.39	1483.78	1760.17	2036.56	2589.34	3142.12	3694.90	4247.68	33.25
33.50	1218.56	1499.12	1779.69	2060.25	2621.38	3182.50	3743.62	4304.75	33.50
33.75	1229.76	1514.53	1799.29	2084.06	2653.59	3223.12	3792.65	4362.18	33.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
34.00	1241.00	1530.00	1819.00	2108.00	2686.00	3264.00	3842.00	4420.00	**34.00**
34.25	1252.26	1545.53	1838.79	2132.06	2718.59	3305.12	3891.65	4478.18	34.25
34.50	1263.56	1561.12	1858.68	2156.25	2751.37	3346.50	3941.62	4536.75	34.50
34.75	1274.89	1576.78	1878.67	2180.56	2784.34	3388.12	3991.90	4595.68	34.75
35.00	1286.25	1592.00	1898.75	2205.00	2817.50	3430.00	4042.50	4655.00	**35.00**
35.25	1297.14	1608.28	1918.92	2229.56	2850.64	3472.12	4093.40	4714.68	35.25
35.50	1309.06	1624.12	1939.18	2254.25	2884.37	3514.50	4144.62	4774.75	35.50
35.75	1320.01	1640.03	1959.54	2279.06	2918.09	3557.12	4196.15	4835.18	35.75
36.00	1332.00	1656.00	1980.00	2304.00	2952.00	3600.00	4248.00	4896.00	**36.00**
36.25	1343.51	1672.03	2000.54	2329.06	2986.09	3643.12	4300.15	4957.18	36.25
36.50	1355.06	1688.12	2021.18	2354.25	3020.37	3686.50	4352.62	5018.75	36.50
36.75	1366.64	1704.28	2041.92	2379.56	3054.84	3730.12	4405.40	5080.68	36.75
37.00	1378.25	1720.50	2062.75	2405.00	3089.50	3774.00	4458.50	5143.05	**37.00**
37.25	1389.89	1736.78	2083.67	2430.56	3124.34	3818.12	4511.90	5205.68	37.25
37.50	1401.56	1753.12	2104.68	2456.25	3159.37	3862.50	4565.62	5268.75	37.50
37.75	1413.01	1769.03	2125.79	2482.06	3194.59	3907.12	4619.65	5332.18	37.75
38.00	1425.00	1786.00	2147.00	2504.00	3230.00	3952.00	4674.00	5396.00	**38.00**
38.25	1436.76	1802.53	2168.29	2534.06	3265.59	3997.12	4728.65	5460.18	38.25
38.50	1448.06	1819.12	2189.68	2560.25	3301.37	4042.50	4783.62	5524.75	38.50
38.75	1460.39	1835.78	2211.05	2586.25	3337.09	4088.12	4839.40	5589.18	38.75
39.00	1472.25	1852.50	2232.75	2613.00	3373.50	4134.00	4894.50	5655.00	**39.00**
39.25	1484.14	1869.28	2254.17	2639.56	3409.34	4180.12	4950.40	5720.68	39.25
39.50	1496.06	1886.12	2276.19	2666.25	3446.37	4226.50	5006.62	5786.75	39.50
39.75	1508.01	1903.03	2298.03	2693.06	3483.09	4273.12	5063.15	5853.18	39.75
40.00	1520.00	1920.00	2320.00	2720.00	3520.00	4320.00	5120.00	5920.00	**40.00**
40.25	1532.01	1937.03	2342.05	2747.06	3557.09	4367.12	5177.15	5987.18	40.25
40.50	1544.06	1954.12	2364.18	2774.25	3594.37	4414.50	5234.62	6054.75	40.50
40.75	1556.14	1971.28	2386.42	2801.56	3631.84	4462.12	5292.40	6122.68	40.75
41.00	1568.25	1988.50	2408.75	2829.00	3669.50	4510.00	5350.50	6191.00	**41.00**
41.25	1580.39	2005.78	2431.17	2856.56	3707.34	4558.12	5408.90	6259.68	41.25
41.50	1592.56	2023.12	2453.68	2884.25	3745.37	4606.50	5467.62	6328.75	41.50
41.75	1604.76	2040.53	2476.05	2912.06	3783.59	4655.12	5526.65	6398.18	41.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
42.00	1617.00	2058.00	2499.00	2940.00	3822.00	4704.00	5586.00	6468.00	**42.00**
42.25	1629.26	2075.53	2521.79	2968.06	3860.59	4753.12	5645.65	6538.18	42.25
42.50	1641.56	2093.12	2544.68	2996.25	3899.37	4802.50	5705.62	6608.75	42.50
42.75	1653.88	2110.77	2567.65	3024.56	3938.52	4852.10	5765.87	6679.65	42.75
43.00	1666.25	2128.50	2590.75	3053.00	3977.50	4902.00	5826.50	6751.00	**43.00**
43.25	1678.64	2146.28	2613.92	3081.56	4016.84	4952.12	5887.40	6822.68	43.25
43.50	1691.06	2164.12	2637.18	3110.25	4056.37	5002.50	5948.62	6894.75	43.50
43.75	1703.51	2182.03	2660.54	3139.06	4096 09	5053.12	6010.15	6967.18	43.75
44.00	1716.00	2200.00	2684.00	3168.00	4136.00	5104.00	6072.00	7040.00	**44.00**
44.25	1728.51	2218.03	2707.54	3197.06	4176.09	5155.12	6134.15	7113.18	44.25
44.50	1741.06	2236.12	2731.18	3226.25	4216.37	5206.50	6196.62	7186.75	44.50
44.75	1753.64	2254.28	2754.92	3255.56	4256.84	5258.12	6259.40	7260.68	44.75
45.00	1766.25	2272.50	2778.75	3285.00	4297.50	5310.00	6322.50	7335.00	**45.00**
45.25	1778.89	2290.78	2802.67	3314.56	4338.34	5362.12	6385.90	7409.68	45.25
45.50	1791.56	2309.12	2826.68	3344.25	4379.37	5414.50	6449.62	7484.75	45.50
45.75	1804.26	2327.53	2850.79	3374.06	4420.59	5467.12	6513.65	7560.18	45.75
46.00	1817.00	2346.00	2875.00	3404.00	4462.00	5520.00	6578.00	7636.00	**46.00**
46.25	1829.76	2364.53	2899.29	3434.06	4503.59	5573.12	6642.65	7712.18	46.25
46.50	1842.56	2383.12	2923.68	3464.25	4545.37	5626.50	6707.62	7788.75	46.50
46.75	1855.39	2401.78	2948.17	3494.56	4587.34	5680.12	6772.90	7865.68	46.75
47.00	1868.25	2420.50	2972.75	3525.00	4629.50	5734.00	6838.50	7943.00	**47.00**
47.25	1881.14	2439.28	2997.42	3555.56	4671.84	5788.12	6904.40	8020.68	47.25
47.50	1894.06	2458.12	3022.18	3586.25	4714.37	5842.50	6970.62	8098.75	47.50
47.75	1907.01	2477.03	3047.04	3617.06	4757.09	5897.12	7037.15	8177.18	47.75
48.00	1920.00	2496.00	3072.00	3648.00	4800.00	5952.00	7104.00	8256.00	**48.00**
48.25	1933.01	2515.03	3097.04	3679.06	4843.09	6007.12	7171.15	8335.18	48.25
48.50	1946.06	2534.12	3122.18	3710.25	4886.37	6062.50	7238.62	8414.75	48.50
48.75	1959.14	2553.28	3147.42	3741.56	4929.84	6118.12	7306.40	8494.68	48.75
49.00	1972.25	2572.50	3172.75	3773.00	4973.50	6174.00	7374.50	8575.00	**49.00**
49.25	1985.39	2591.78	3198.17	3804.56	5017.34	6230.12	7442.90	8655.68	49.25
49.50	1998.56	2611.12	3223.68	3836.25	5061.37	6286.50	7511.62	8736.75	49.50
49.75	2011.76	2630.53	3249.29	3868.06	5105.59	6343.12	7580.65	8816.18	49.75

BASE 28.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
50.00	2025.00	2650.00	3275.00	3900.00	5150.00	6400.00	7650.00	8900.00	**50.00**
50.25	2038.26	2669.53	3300.79	3932.06	5194.59	6457.12	7719.65	8982.18	50.25
50.50	2051.56	2689.12	3326.68	3964.25	5239.37	6514.50	7789.62	9064.75	50.50
50.75	2064.89	2708.78	3352.67	3996.56	5284.34	6572.12	7859.90	9147.68	50.75
51.00	2078.25	2728.50	3378.75	4029.00	5329.50	6630.00	7930.50	9231.00	**51.00**
51.25	2091.64	2748.28	3404.92	4061.56	5374.84	6688.12	8001.40	9314.68	51.25
51.50	2105.06	2768.12	3431.18	4094.25	5420.37	6746.50	8072.62	9398.75	51.50
51.75	2118.51	2788.03	3457.04	4127.06	5466.09	6805.12	8144.15	9483.18	51.75
52.00	2132.00	2808.00	3484.00	4160.00	5512.00	6864.00	8216.00	9568.00	**52.00**
52.25	2145.51	2828.03	3510.54	4193.06	5558.09	6923.12	8288.15	9653.18	52.25
52.50	2159.06	2848.12	3537.18	4226.25	5604.37	6982.50	8360.62	9738.75	52.50
52.75	2172.64	2868.28	3563.92	4259.56	5650.84	7042.12	8433.40	9824.68	52.75
53.00	2186.25	2888.50	3590.75	4293.00	5697.50	7102.00	8506.50	9913.00	**53.00**
53.25	2199.89	2908.78	3617.67	4326.56	5744.34	7162.12	8579.90	9997.68	53.25
53.50	2213.56	2929.12	3644.68	4360.25	5791.37	7222.50	8653.62	10084.75	53.50
53.75	2227.26	2949.53	3671.79	4394.06	5838.59	7283.12	8727.65	10162.18	53.75
54.00	2241.00	2970.00	3699.00	4428.00	5886.00	7344.00	8802.00	10260.00	**54.00**
54.25	2254.76	2990.53	3726.29	4462.06	5933.59	7405.12	8876.65	10348.18	54.25
54.50	2268.56	3011.12	3753.68	4496.25	5981.37	7466.50	8951.62	10436.75	54.50
54.75	2282.39	3031.78	3781.67	4530.56	6029.34	7528.12	9026.90	10525.68	54.75
55.00	2296.25	3052.50	3808.75	4565.00	6077.50	7590.00	9102.50	10615.00	**55.00**
55.25	2310.14	3073.28	3836.42	4599.56	6125.84	7652.12	9178.40	10704.68	55.25
55.50	2324.06	3094.12	3864.18	4634.25	6174.37	7714.50	9254.62	10794.75	55.50
55.75	2338.01	3115.03	3892.04	4669.06	6223.09	7777.12	9332.15	10885.18	55.75
56.00	2352.00	3136.00	3920.00	4704.00	6272.00	7840.00	9408.00	10976.00	**56.00**
56.25	2366.01	3157.03	3948.04	4739.06	6321.09	7903.12	9485.15	11067.18	56.25
56.50	2380.06	3178.12	3976.18	4774.25	6370.37	7966.50	9562.62	11158.75	56.50
56.75	2394.14	3199.28	4004.42	4809.56	6419.84	8030.12	9640.40	11249.68	56.75
57.00	2408.25	3220.50	4032.75	4835.00	6469.50	8094.00	9718.50	11342.00	**57.00**
57.25	2422.39	3241.78	4061.17	4880.56	6519.34	8158.12	9796.90	11435.68	57.25
57.50	2436.56	3263.12	4089.68	4916.25	6569.37	8222.50	9875.62	11528.75	57.50
57.75	2450.76	3284.53	4118.29	4952.06	6619.59	8287.12	9954.65	11622.18	57.75

BASE 30.—*Sectional Areas n Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1	2 to 1.	2½ to 1.	3 to 1.	Depths.
1.00	30.25	30.50	30.75	31.00	31.50	32.00	32.50	33.00	**1.00**
2.00	61.00	62.00	63.00	64.00	66.00	68.00	70.00	72.00	2.00
3.00	92.25	94.00	99.75	99.00	103.50	108.00	112.50	117.00	3.00
4.00	124.00	128.00	132.00	136.00	144.00	152.00	160.00	168.00	4.00
5.00	156.25	162.50	168.75	175.00	187.50	200.00	212.50	225.00	**5.00**
6.00	189.00	198.00	207.00	216.00	234.00	252.00	270.00	288.00	6.00
7.00	222.25	234.50	246.75	259.00	283.50	308.00	332.50	357.00	7.00
8.00	256.00	272.00	288.00	304.00	336.00	368.00	400.00	432.00	8.00
9.00	290.25	310.50	330.75	351.00	391.50	432.00	472.50	513.00	**9.00**
10.00	325.00	350.00	375.00	400.00	450.00	500.00	550.00	600.00	10.00
11.00	360.25	390.50	420.75	451.00	511.50	572.00	632.00	693.00	11.00
12.00	396.00	432.00	463.00	504.00	576.00	648.00	720.00	792.00	12.00
13.00	432.25	474.50	516.75	559.00	643.50	728.00	812.50	897.00	**13.00**
13.25	441.35	485.21	529.17	573.06	660.84	748.62	836.33	924.18	13.25
13.50	450.56	496.12	541.68	587.24	678.36	769.48	860.60	951.62	13.50
13.75	459.76	506.03	554.30	601.56	696.09	790.62	885.15	979.78	13.75
14.00	469.00	518.00	567.00	616.00	714.00	812.00	910.00	1008.00	**14.00**
14.25	478.26	528.03	579.80	630.56	731.09	833.62	935.15	1036.68	14.25
14.50	487.56	540.12	592.69	645.25	750.38	855.50	960.62	1065.75	14.50
14.75	496.78	551.23	605.60	659.96	768.69	877.62	986.35	1094.88	14.75
15.00	506.25	562.50	618.75	675.00	787.50	900.00	1012.50	1125.00	**15.00**
15.25	515.63	573.76	631.92	690.06	806.34	922.62	1038.88	1155.18	15.25
15.50	525.06	585.12	645.19	705.25	825.38	945.50	1065.62	1185.75	15.50
15.75	534.51	596.53	658.55	720.56	844.59	968.62	1092.65	1216.68	15.75
16.00	544.00	608.00	672.00	736.00	864.00	992.00	1120.00	1248.00	**16.00**
16.25	553.51	619.53	685.55	751.56	883.59	1015.62	1147.65	1279.68	16.25
16.50	563.06	631.12	699.19	767.25	903.38	1039.50	1175.62	1311.75	16.50
16.75	572.63	642.76	712.92	783.06	923.34	1063.62	1203.88	1344.18	16.75
17.00	582.25	654.50	726.75	799.00	943.50	1088.00	1232.50	1377.00	**17.00**
17.25	591.88	666.26	740.64	815.02	963.78	1112.89	1261.65	1410.06	17.25
17.50	601.50	678.12	754.69	831.25	984.38	1137.50	1290.62	1443.75	17.50
17.75	611.26	690.02	768.80	847.56	1005.09	1162.62	1320.14	1477.68	17.75

BASE 30.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
18.00	621.00	702.00	783.00	864.00	1026.00	1188.00	1350.00	1512.00	**18.00**
18.25	630.76	714.03	797.29	880.56	1046.09	1213.62	1380.15	1546.68	18.25
18.50	640.56	726.12	811.69	897.25	1068.38	1239.38	1410.62	1581.75	18.50
18.75	650.37	738.25	826.12	914.00	1089.75	1265.50	1441.25	1617.00	18.75
19.00	660.25	750.50	840.70	931.00	1111.50	1292.00	1472.50	1653.00	**19.00**
19.25	670.14	762.78	855.42	948.06	1133.34	1318.62	1503.90	1689.18	19.25
19.50	680.06	775.12	870.19	965.25	1155.38	1345.50	1535.62	1725.75	19.50
19.75	690.01	787.53	884.05	982.56	1177.59	1372.62	1567.65	1752.68	19.75
20.00	700.00	800.00	900.00	1000.00	1200.00	1400.00	1600.00	1800.00	**20.00**
20.25	710.01	812.53	914.05	1017.56	1222.59	1427.62	1632.65	1837.68	20.25
20.50	720.06	826.12	930.19	1035.25	1255.38	1455.50	1665.62	1875.75	20.50
20.75	730.13	837.76	945.42	1052.06	1268.34	1483.62	1698.88	1914.18	20.75
21.00	740.25	850.50	960.75	1071.00	1291.50	1512.00	1732.50	1953.00	**21.00**
21.25	750.39	863.28	976.17	1089.05	1314.84	1540.62	1766.40	1992.18	21.25
21.50	760.24	876.12	991.68	1107.25	1338.38	1569.50	1800.62	2031.75	21.50
21.75	770.60	888.03	1006.77	1125.56	1362.04	1598.62	1835.15	2071.68	21.75
22.00	781.00	902.00	1023.00	1144.00	1386.00	1628.00	1870.00	2112.00	**22.00**
22.25	791.26	914.03	1037.77	1162.56	1410.04	1657.62	1905.15	2152.68	22.25
22.50	801.50	928.12	1054.69	1181.25	1434.38	1687.50	1940.62	2193.75	22.50
22.75	811.89	940.28	1070.67	1200.06	1458.84	1717.62	1976.40	2235.18	22.75
23.00	822.25	954.50	1086.75	1219.00	1483.50	1748.00	2012.50	2277.00	**23.00**
23.25	832.62	967.75	1102.92	1238.06	1508.34	1778.62	2048.87	2319.18	23.25
23.50	843.00	981.12	1119.19	1257.25	1533.38	1809.50	2085.62	2361.75	23.50
23.75	853.39	994.53	1135.55	1276.56	1558.59	1840.62	2122.65	2404.68	23.75
24.00	864.00	1008.00	1152.00	1296.00	1584.00	1872.00	2160.00	2448.00	**24.00**
24.25	874.51	1021.53	1168.55	1315.56	1609.59	1903.62	2197.65	2491.68	24.25
24.50	885.06	1035.12	1185.19	1335.25	1635.38	1935.50	2235.62	2535.75	24.50
24.75	895.64	1048.78	1201.67	1355.06	1660.84	1967.62	2273.70	2580.18	24.75
25.00	906.25	1062.50	1218.75	1375.00	1687.50	2000.00	2312.50	2625.00	**25.00**
25.25	916.89	1076.28	1235.67	1395.06	1713.84	2032.12	2351.30	2670.18	25.25
25.50	927.56	1090.12	1252.69	1415.25	1740.38	2065.50	2390.62	2715.75	25.50
25.75	938.26	1104.03	1269.55	1435.56	1766.59	2098.62	2430.15	2761.68	25.75

BASE 30.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
26.00	949.00	1118.00	1287.00	1456.00	1794.00	2132.00	2470.00	2808.00	**26.00**
26.25	959.76	1132.03	1304.29	1476.56	1821.09	2165.62	2510.15	2854.68	26.25
26.50	970.56	1146.13	1321.69	1497.25	1848.37	2199.50	2550.62	2901.75	26.50
26.75	981.39	1160.28	1339.17	1518.06	1875.84	2233.62	2591.40	2949.18	26.75
27.00	992.25	1174.50	1356.75	1539.00	1903.50	2268.00	2632.50	2997.00	**27.00**
27.25	1003.14	1188.78	1373.92	1560.06	1931.34	2302.62	2673.90	3046.68	27.25
27.50	1014.06	1203.12	1392.18	1581.25	1959.37	2337.50	2715.62	3093.75	27.50
27.75	1025.01	1217.53	1410.04	1602.56	1987.59	2372.62	2757.65	3142.68	27.75
28.00	1036.00	1232.00	1428.00	1624.00	2016.00	2408.00	2800.00	3192.00	**28.00**
28.25	1047.01	1246.53	1446.04	1645.56	2044.59	2443.62	2842.65	3241.68	28.25
28.50	1058.06	1261.12	1464.18	1667.25	2073.37	2479.50	2885.62	3291.75	28.50
28.75	1069.14	1275.28	1482.42	1688.56	2101.84	2515.62	2928.90	3341.68	28.75
29.00	1080.25	1290.50	1500.75	1711.00	2131.50	2552.00	2972.50	3393.00	**29.00**
29.25	1091.39	1305.28	1519.17	1733.06	2160.84	2588.62	3016.40	3444.18	29.25
29.50	1102.56	1320.12	1539.93	1755.25	2190.37	2625.50	3060.62	3495.75	29.50
29.75	1113.76	1345.03	1556.29	1777.56	2220.09	2662.62	3105.15	3547.68	29.75
30.00	1125.00	1350.00	1575.00	1800.00	2250.00	2700.00	3150.00	3600.00	**30.00**
30.25	1136.26	1365.03	1593.80	1822.56	2280.09	2737.62	3195.15	3652.68	30.25
30.50	1147.56	1380.12	1612.69	1845.25	2310.37	2775.50	3240.62	3705.75	30.50
30.75	1158.89	1395.28	1631.54	1868.06	2340.59	2813.62	3286.15	3758.68	30.75
31.00	1170.25	1410.50	1650.25	1891.00	2371.50	2852.00	3332.50	3813.00	**31.00**
31.25	1181.64	1425.78	1669.92	1914.06	2402.34	2890.62	3378.90	3867.18	31.25
31.50	1193.06	1441.12	1689.19	1937.25	2433.37	2929.50	3425.62	3921.75	31.50
31.75	1204.51	1456.53	1708.55	1960.56	2464.59	2968.62	3472.65	3976.68	31.75
32.00	1216.00	1472.00	1728.00	1984.00	2496.00	3008.00	3520.00	4032.00	**32.00**
32.25	1227.51	1487.53	1747.55	2007.56	2527.59	3047.62	3567.65	4087.68	32.25
32.50	1239.06	1503.12	1767.18	2031.25	2559.37	3087.50	3615.62	4143.75	32.50
32.75	1250.64	1518.78	1786.67	2055.06	2590.84	3127.62	3663.90	4199.18	32.75
33.00	1262.25	1534.50	1806.75	2079.00	2623.50	3168.00	3712.50	4257.00	**33.00**
33.25	1273.89	1550.28	1826.67	2103.06	2655.84	3208.62	3761.40	4314.18	33.25
33.50	1285.56	1566.12	1846.69	2127.25	2688.38	3249.50	3810.62	4371.75	33.50
33.75	1297.26	1582.03	1866.79	2151.56	2721.09	3290.62	3860.15	4429.68	33.75

BASE 30.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1	3 to 1.	Depths.
34.00	1309.00	1598.00	1887.00	2171.00	2754.00	3332.00	3910.00	4488.00	**34.00**
34.25	1320.76	1614.03	1907.29	2200.56	2787.09	3373.62	3960.15	4546.68	34.25
34.50	1332.56	1630.12	1927.68	2225.25	2820.37	3415.50	4010.62	4605.75	34.50
34.75	1344.39	1646.28	1948.17	2250.06	2853.84	3457.62	4061.40	4665.18	34.75
35.00	1356.25	1662.50	1968.75	2275.00	2887.50	3500.00	4112.50	4725.00	**35.00**
35.25	1367.64	1678.78	1989.42	2300.06	2921.34	3542.62	4163.90	4785.18	35.25
35.50	1380.06	1695.12	2010.18	2325.25	2955.37	3585.50	4215.62	4845.75	35.50
35.75	1391.51	1711.53	2031.04	2351.56	2989.59	3628.62	4267.65	4906.68	35.75
36.00	1404.00	1728.00	2052.00	2376.00	3024.00	3672.00	4320.00	4968.00	**36.00**
36.25	1416.01	1744.53	2073.04	2401.56	3058.59	3715.62	4372.65	5029.68	36.25
36.50	1428.06	1761.12	2094.18	2427.25	3093.37	3759.50	4425.62	5091.75	36.50
36.75	1440.14	1777.78	2115.42	2453.06	3128.34	3803.62	4478.90	5154.18	36.75
37.00	1452.25	1794.50	2136.75	2479.00	3163.50	3848.00	4532.50	5217.00	**37.00**
37.25	1464.39	1811.28	2158.17	2505.06	3198.84	3892.62	4586.40	5280.18	37.25
37.50	1476.56	1828.12	2179.68	2531.27	3234.37	3937.50	4640.62	5343.75	37.50
37.75	1488.51	1844.53	2201.29	2557.56	3270.09	3982.62	4695.15	5407.68	37.75
38.00	1501.00	1862.00	2223.00	2584.00	3306.00	4028.00	4750.00	5472.00	**38.00**
38.25	1513.26	1879.03	2244.79	2610.56	3342.09	4073.62	4805.15	5536.68	38.25
38.50	1525.06	1896.12	2266.68	2637.25	3378.37	4119.50	4860.62	5601.75	38.50
38.75	1537.89	1913.28	2288.55	2664.06	3414.59	4165.62	4916.50	5666.68	38.75
39.00	1550.25	1930.50	2310.75	2691.00	3451.50	4212.00	4972.50	5733.00	**39.00**
39.25	1562.64	1947.78	2332.67	2718.06	3487.84	4258.62	5038.90	5799.18	39.25
39.50	1575.06	1965.12	2355.19	2745.25	3525.37	4305.50	5085.62	5865.75	39.50
39.75	1587.51	1982.53	2377.53	2772.56	3562.59	4352.62	5142.65	5932.68	39.75
40.00	1600.00	2000.00	2400.00	2800.00	3600.00	4400.00	5200.00	6000.00	**40.00**
40.25	1612.51	2017.53	2422.55	2827.56	3637.59	4447.62	5257.15	6067.68	40.25
40.50	1625.06	2035.12	2445.18	2855.25	3675.37	4495.50	5315.62	6135.75	40.50
40.75	1637.64	2052.78	2467.92	2883.06	3713.34	4543.62	5373.90	6204.18	40.75
41.00	1650.25	2070.50	2490.75	2911.00	3751.50	4592.00	5432.50	6273.00	**41.00**
41.25	1662.89	2088.28	2513.67	2939.06	3789.84	4640.62	5490.40	6342.18	41.25
41.50	1675.56	2106.12	2536.68	2967.25	3828.37	4689.50	5550.62	6411.75	41.50
41.75	1688.26	2124.03	2559.55	2995.56	3867.09	4738.62	5609.15	6481.68	41.75

BASE 30.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
42.00	1701.00	2142.00	2583.00	3024.00	3906.00	4788.00	5670.00	6552.00	**42.00**
42.25	1713.76	2160.03	2606.29	3052.56	3945.09	4837.62	5730.15	6622.68	42.25
42.50	1726.56	2178.12	2629.68	3081.25	3984.37	4887.50	5790.62	6693.75	42.50
42.75	1739.38	2206.27	2653.15	3110.05	4023.82	4937.62	5851.37	6765.15	42.75
43.00	1752.25	2214.50	2676.75	3139.00	4063.50	4988.00	5912.50	6837.00	**43.00**
43.25	1765.14	2232.78	2700.42	3168.06	4103.34	5038.62	5973.90	6909.18	43.25
43.50	1778.06	2251.12	3724.18	3197.25	4143.37	5089.50	6035.62	6981.75	43.50
43.75	1791.01	2269.53	2748.04	3226.56	4183.59	5140.62	6097.65	7054.68	43.75
44.00	1804.00	2288.00	2772.00	3256.00	4224.00	5192.00	6160.00	7128.00	**44.00**
44.25	1817.01	2306.53	2795.04	3285.56	4264.59	5243.62	6222.65	7201.68	44.25
44.50	1830.06	2325.12	2820.18	3315.25	4305.37	5295.50	6285.62	7275.75	44.50
44.75	1843.14	2343.78	2844.42	3345.06	4346.34	5347.62	6348.90	7350.18	44.75
45.00	1856.25	2362.50	2868.75	3375.00	4387.50	5400.00	6412.56	7425.00	**45.00**
45.25	1869.39	2381.28	2893.17	3405.06	4429.84	5452.62	6476.40	7500.18	45.25
45.50	1882.56	2400.12	2917.68	3435.25	4470.37	5505.50	6540.62	7575.75	45.50
45.75	1895.76	2419.03	2942.29	3465.56	4512.09	5558.62	6605.15	7651.68	45.75
46.00	1909.00	2438.00	2967.00	3496.00	4554.00	5612.00	6670.00	7728.00	**46.00**
46.25	1922.26	2457.03	2991.79	3526.56	4596.09	5665.62	6735.15	7804.68	46.25
46.50	1935.56	2476.12	3016.68	3557.25	4638.37	5719.50	6800.62	7881.75	46.50
46.75	1948.89	2495.28	3041.67	3588.06	4680.84	5773.62	6860.40	7959.18	46.75
47.00	1962.25	2514.50	3066.75	3619.00	4723.50	5828.00	6932.50	8037.00	**47.00**
47.25	1975.64	2533.78	3091.92	3650.06	4766.34	5882.62	6998.90	8115.18	47.25
47.50	1989.06	2553.12	3117.18	3681.25	4809.37	5937.50	7065.62	8193.75	47.50
47.75	2002.51	2572.53	3142.54	3712.56	4852.59	5992.62	7132.65	8272.68	47.75
48.00	2016.00	2592.00	3168.00	3744.00	4896.00	6048.00	7200.00	8352.00	**48.00**
48.25	2029.51	2611.53	3193.54	3775.56	4939.59	6103.62	7267.65	8431.68	48.25
48.50	2043.06	2631.12	3219.18	3807.25	4983.37	6159.50	7335.62	8511.75	48.50
48.75	2056.64	2650.78	3244.92	3839.06	5027.34	6215.62	7403.90	8592.18	48.75
49.00	2070.25	2670.50	3270.75	3871.00	5071.50	6272.00	7472.50	8673.00	**49.00**
49.25	2083.89	2690.28	3296.67	3903.06	5115.84	6328.62	7541.40	8753.18	49.25
49.50	2097.56	2710.12	3322.68	3935.25	5160.37	6385.50	7610.62	8835.75	49.50
49.75	2111.26	2730.03	3348.79	3967.56	5205.09	6442.62	7680.15	8917.68	49.75

BASE 30.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
50.00	2125.00	2750.00	3375.00	4000.00	5250.00	6500.00	7750.00	9000.00	**50.00**
50.25	2138.76	2770.03	3401.29	4032.56	5295.09	6557.62	7820.15	9082.68	50.25
50.50	2152.56	2790.12	3427.68	4065.25	5340.37	6615.50	7890.62	9165.75	50.50
50.75	2166.39	2810.28	3454.17	4098.06	5385.84	6673.62	7961.40	9249.18	50.75
51.00	2180.25	2830.50	3480.75	4131.00	5431.50	6732.00	8032.50	9333.00	**51.00**
51.25	2194.14	2850.78	3507.42	4164.06	5477.34	6790.62	8103.90	9417.18	51.25
51.50	2208.06	2871.12	3534.18	4197.25	5523.37	6849.50	8175.62	9501.75	51.50
51.75	2222.01	2891.53	3560.54	4230.56	5569.59	6908.62	8247.65	9586.68	51.75
52.00	2236.00	2912.00	3588.00	4264.00	5616.00	6968.00	8320.00	9672.00	**52.00**
52.25	2250.61	2932.53	3615.04	4297.56	5662.59	7027.62	8392.65	9767.68	52.25
52.50	2264.06	2953.12	3642.18	4331.25	5709.37	7087.50	8465.62	9843.75	52.50
52.75	2278.14	2973.78	3669.42	4365.06	5756.34	7147.62	8538.90	9930.18	52.75
53.00	2292.25	2994.50	3696.75	4399.00	5803.50	7208.00	8612.50	10017.00	**53.00**
53.25	2306.39	3015.28	3724.17	4433.06	5850.84	7268.62	8686.40	10104.18	53.25
53.50	2320.56	3036.12	3751.68	4467.25	5898.37	7329.50	8760.62	10191.75	53.50
53.75	2334.76	3057.03	3779.29	4501.56	5946.09	7390.62	8835.15	10279.68	53.75
54.00	2349.00	3078.00	3807.00	4536.00	5994.00	7452.00	8910.00	10368.00	**54.00**
54.25	2363.26	3099.03	3834.79	4570.56	6042.09	7513.62	8985.15	10456.68	54.25
54.50	2377.56	3120.12	3862.68	4605.25	6090.37	7575.50	9060.62	10545.75	54.50
54.75	2391.89	3141.28	3891.17	4640.06	6138.84	7637.62	9136.40	10635.18	54.75
55.00	2406.25	3162.50	3918.75	4675.00	6187.50	7700.00	9212.50	10725.00	**55.00**
55.25	2420.64	3183.78	3946.92	4710.06	6236.34	7762.62	9288.90	10815.18	55.25
55.50	2435.06	3205.12	3975.18	4745.25	6285.37	7825.50	9365.62	10905.75	55.50
55.75	2449.51	3226.53	4003.54	4780.56	6334.59	7888.62	9443.65	10996.68	55.75
56.00	2464.00	3248.00	4032.00	4816.00	6384.00	7952.00	9520.00	11088.00	**56.00**
56.25	2478.51	3269.53	4060.54	4851.56	6433.59	8015.62	9597.65	11179.68	56.25
56.50	2493.06	3291.12	4089.18	4887.25	6483.37	8079.50	9675.62	11271.75	56.50
56.75	2507.64	3312.78	4117.92	4923.06	6533.34	8143.62	9753.90	11363.18	56.75
57.00	2522.25	3334.50	4146.75	4959.00	6583.50	8208.00	9832.50	11457.00	**57.00**
57.25	2536.89	3356.28	4176.67	4995.06	6633.84	8272.62	9910.40	11550.18	57.25
57.50	2551.56	3378.12	4204.68	5031.25	6684.37	8337.50	9990.62	11643.75	57.50
57.75	2566.26	3400.03	4233.79	5067.56	6735.09	8402.62	10070.15	11737.68	57.75

BASE 31.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1	2 to 1.	2½ to 1.	3 to 1.	Depths.
1.00	31.25	31.50	31.75	32.00	32.50	33.00	33.50	34.00	**1.00**
2.00	63.00	64.00	65.00	66.00	68.00	70.00	72.00	74.00	2.00
3.00	95.25	97.50	99.75	102.00	106.50	111.00	115.50	120.00	3.00
4.00	128.00	132.00	136.00	140.00	148.00	156.00	164.00	172.00	4.00
5.00	161.25	167.50	173.75	180.00	192.50	205.00	217.50	230.00	**5.00**
6.00	195.00	204.00	213.00	222.00	240.00	258.00	276.00	294.00	6.00
7.00	229.25	241.50	253.75	266.00	290.50	315.00	339.50	364.00	7.00
8.00	264.00	280.00	296.00	312.00	344.00	376.00	408.00	440.00	8.00
9.00	299.25	319.50	339.75	360.00	400.50	441.00	481.50	522.00	**9.00**
10.00	335.00	360.00	385.00	410.00	460.00	510.00	560.00	610.00	10.00
11.00	371.25	401.50	431.75	462.00	522.50	583.00	643.00	704.00	11.00
12.00	408.00	444.00	475.00	516.00	588.00	660.00	732.00	804.00	12.00
13.00	445.25	487.50	529.75	572.00	656.50	741.00	825.50	910.00	**13.00**
13.25	454.60	498.46	542.42	586.31	674.09	761.87	849.58	937.43	13.25
13.50	464.06	509.62	555.18	600.74	691.86	782.98	874.10	965.22	13.50
13.75	473.51	520.78	568.05	615.31	709.84	804.37	898.90	993.43	13.75
14.00	483.00	532.00	581.00	630.00	728.00	826.00	924.00	1022.00	**14.00**
14.25	492.51	543.28	594.05	644.81	746.34	847.87	949.40	1050.93	14.25
14.50	502.06	554.62	607.19	659.75	764.88	870.00	975.12	1080.25	14.50
14.75	511.53	565.98	620.35	674.71	783.44	892.37	1001.10	1109.63	14.75
15.00	521.25	577.50	633.75	690.00	802.50	915.00	1027.50	1140.00	**15.00**
15.25	530.88	589.01	647.17	705.31	821.59	937.87	1054.13	1170.43	15.25
15.50	540.56	600.62	660.59	720.75	840.88	961.00	1081.12	1201.25	15.50
15.75	550.26	612.28	674.30	736.61	860.34	984.37	1108.40	1232.43	15.75
16.00	560.00	624.00	688.00	752.00	880.00	1008.00	1136.00	1264.00	**16.00**
16.25	569.76	635.78	701.80	767.81	899.84	1031.87	1163.90	1295.93	16.25
16.50	579.56	647.62	715.69	783.75	919.88	1056.00	1192.12	1328.25	16.50
16.75	589.38	659.51	729.67	799.81	940.09	1080.37	1220.63	1360.93	16.75
17.00	599.25	671.50	743.75	816.00	960.50	1105.00	1249.50	1394.00	**17.00**
17.25	609.13	683.51	757.89	832.27	981.03	1130.14	1278.90	1427.31	17.25
17.50	619.06	695.62	772.19	848.75	1001.88	1155.00	1308.12	1461.25	17.50
17.75	629.01	707.77	786.55	865.31	1022.84	1180.37	1337.89	1495.43	17.75

BASE 31.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
18.00	639.00	720.00	801.00	882.00	1044.00	1206.00	1368.00	1530.00	18.00
18.25	649.01	732.28	815.54	898.81	1065.34	1231.87	1398.40	1564.93	18.25
18.50	659.06	744 62	830.19	915.75	1086.88	1258.00	1429.12	1600.25	18.50
18.75	669.12	757.00	844.87	932.75	1108.50	1284.25	1460.00	1635.75	18.75
19.00	679.25	769.50	859.70	950.00	1130 50	1311.00	1491.50	1672.00	19.00
19.25	689.39	782.03	874.67	967.31	1152.59	1337.87	1523.15	1708.43	19.25
19.50	699.56	794.62	889.69	984.75	1174.88	1365.00	1555.12	1745.25	19.50
19.75	709.76	807.28	904.80	1002.31	1197.34	1392.37	1587.40	1782.43	19.75
20.00	720.00	820.00	920.00	1020.00	1220.00	1420.00	1620.00	1820.00	20.00
20.25	730.26	832.78	935.30	1037.81	1242.84	1447.87	1652.90	1857.93	20.25
20.50	740.56	845.62	950.69	1055.75	1265.88	1475.00	1686.12	1896.25	20.50
20.75	750.88	858.51	966.17	1073.81	1289.00	1504.37	1719.63	1934.93	20.75
21.00	761.25	871.50	981.75	1092.00	1312.50	1533.00	1753.50	1974.00	21.00
21.25	771.64	884.53	997.42	1110.31	1336.09	1561.87	1787.65	2013.43	21.25
21.50	781.74	897.62	1013.18	1128.75	1359.88	1591.00	1822.12	2053.25	21.50
21.75	792.35	910.78	1028.52	1147.31	1383.79	1620.37	1856.90	2093.43	21.75
22.00	803.00	924.00	1045.00	1166.00	1408.00	1650.00	1892.00	2134.00	22.00
22.25	814.51.	938.28	1061.02	1185.81	1433.29	1680.87	1928.40	2175.93	22.25
22.50	825.00	951.62	1078.19	1204.75	1457.88	1711.00	1964.12	2217.25	22.50
22.75	835.64	965.03	1094.42	1223.81	1482.59	1741.37	2000.15	2258.93	22.75
23.00	846.25	978.50	1110.75	1243.00	1507.50	1772.00	2036.50	2301.00	23.00
23.25	856.87	992.00	1127.17	1262.31	1532.59	1802.87	2073.13	2343.43	23.25
23.50	867.50	1005.62	1143.69	1281.75	1557.88	1834.00	2110.12	2386.25	23.50
23.75	877.26	1018.28	1159.30	1300.31	1582.34	1864.37	2146.40	2428.43	23.75
24.00	888.00	1032.00	1176.00	1320.00	1608.00	1896.00	2184.00	2472.00	24.00
24.25	898.76	1045.78	1192.80	1339.81	1633.84	1927.87	2221.90	2515.93	24.25
24.50	909.56	1059.62	1209.69	1359.75	1659.88	1960.00	2260.12	2560.25	24.50
24.75	920.39	1073.53	1226.42	1379.81	1685.59	1992.37	2298.45	2603.93	24.75
25.00	931.25	1087.50	1243.75	1400.00	1712.50	2025.00	2337.50	2650.00	25.00
25.25	942.14	1101.53	1260.92	1420.31	1739.09	2057.87	2376.55	2695.43	25.25
25.50	953.06	1115.62	1278.19	1440.75	1765 88	2090.00	2416.12	2741.25	25.50
25.75	964.01	1129.78	1295.30	1461.31	1792.34	2124.37	2455.90	2787.43	25.75

BASE 31.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
26.00	975.00	1144.00	1313.00	1482.00	1820.00	2158.00	2496.00	2834.00	**26.00**
26.25	986.01	1158.28	1330.54	1502.81	1847.34	2191.87	2536.40	2880.93	26.25
26.50	987.06	1172.63	1348.19	1523.75	1874.87	2226.00	2577.12	2928.25	26.50
26.75	1008.14	1187.03	1365.92	1544.81	1902.59	2260.37	2618.15	2975.93	26.75
27.00	1019.25	1201.50	1383.75	1566.00	1930.50	2295.00	2659.50	3024.00	**27.00**
27.25	1030.39	1216.03	1401.17	1587.31	1958.59	2329.87	2701.15	3073.93	27.25
27.50	1041.56	1230.62	1419.68	1608.75	1986.87	2365.00	2743.12	3121.25	27.50
27.75	1052.76	1245.28	1437.79	1630.31	2015.34	2400.37	2785.30	3170.43	27.75
28.00	1064.00	1260.00	1456.00	1652.00	2044.00	2436.00	2828.00	3220.00	**28.00**
28.25	1075.26	1274.78	1474.29	1673.81	2072.84	2471.87	2870.90	3269.93	28.25
28.50	1086.56	1289.62	1492.68	1695.75	2101.87	2508.00	2914.12	3320.25	28.50
28.75	1097.89	1304.53	1511.17	1717.81	2131.09	2544.37	2957.65	3370.93	28.75
29.00	1109.25	1319.50	1529.75	1740.00	2160.50	2581.00	3001.50	3422.00	**29.00**
29.25	1120.64	1334.53	1548.42	1762.31	2190.09	2617.87	3045.65	3473.43	29.25
29.50	1132.06	1349.62	1567.40	1784.75	2219.87	2655.00	3090.12	3525.25	29.50
29.75	1143.51	1364.78	1586.04	1807.31	2249.84	2692.37	3134.90	3577.43	29.75
30.00	1155.00	1380.00	1605.00	1830.00	2280.00	2730.00	3180.00	3630.00	**30.00**
30.25	1166.51	1395.28	1624.05	1852.81	2310.34	2767.87	3225.40	3682.93	30.25
30.50	1178.06	1410.62	1643.19	1875.75	2340.87	2806.00	3271.12	3736.25	30.50
30.75	1189.64	1426.03	1662.29	1898.81	2371.34	2844.37	3316.90	3789.43	30.75
31.00	1201.25	1441.50	1681.25	1922.00	2402.50	2883.00	3363.50	3844.00	**31.00**
31.25	1212.89	1457.03	1701.17	1945.31	2433.59	2921.87	3410.15	3898.44	31.25
31.50	1224.56	1472.62	1720.69	1968.75	2464.87	2961.00	3457.12	3953.25	31.50
31.75	1236.26	1488.28	1740.30	1992.31	2496.34	3000.37	3504.40	4008.43	31.75
32.00	1248.00	1504.00	1760.00	2016.00	2528.00	3040.00	3552.00	4064.00	**32.00**
32.25	1259.76	1519.78	1779.80	2039.81	2559.84	3079.87	3599.90	4119.93	32.25
32.50	1271.56	1535.62	1799.68	2063.75	2591.87	3120.00	3648.12	4176.25	32.50
32.75	1283.39	1551.53	1819.42	2087.81	2623.59	3160.37	3696.65	4232.93	32.75
33.00	1295.25	1567.50	1839.75	2112.00	2656.50	3201.00	3745.50	4290.00	**33.00**
33.25	1307.14	1583.53	1859.92	2136.31	2689.09	3241.87	3794.65	4347.43	33.25
33.50	1319.06	1599.62	1880.19	2160.75	2721.88	3283.00	3844.12	4405.25	33.50
33.75	1331.01	1615.78	1900.54	2185.31	2754.84	3324.37	3893.90	4463.43	33.75

BASE 31.—*Sectional Areas in Feet.*

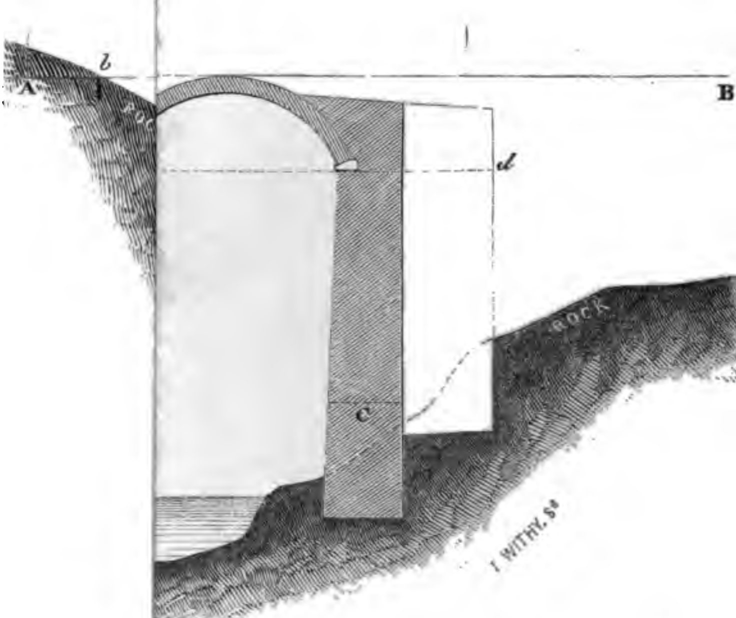
Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
34.00	1343.00	1632.00	1921.00	2210.00	2788.00	3366.00	3944.00	4522.00	**34.00**
34.25	1355.01	1648.28	1941.54	2234.81	2821.34	3407.87	3994.60	4580.93	34.25
34.50	1367.06	1664.62	1962.18	2259.75	2854.87	3450.00	4045.12	4640.25	34.50
34.75	1379.14	1681.03	1982.92	2284.81	2888.59	3492.37	4096.15	4699.93	34.75
35.00	1391.25	1697.00	2003.75	2310.00	2922.50	3535.00	4147.50	4760.00	**35.00**
35.25	1402.89	1714.03	2024.67	2335.31	2956.59	3577.87	4199.15	4820.43	35.25
35.50	1415.56	1730.62	2045.68	2360.75	2990.87	3621.00	4251.12	4881.25	35.50
35.75	1427.26	1747.28	2066.79	2386.31	3025.34	3664.37	4303.40	4942.32	35.75
36.00	1440.00	1764.00	2088.00	2412.00	3060.00	3708.00	4356.00	5004.00	**36.00**
36.25	1452.26	1780.78	2109.29	2437.81	3094.84	3751.87	4408.90	5065.93	36.25
36.50	1464.56	1797.62	2130.68	2463.75	3129.87	3796.00	4462.12	5128.25	36.50
36.75	1476.89	1814.53	2152.17	2489.81	3165.09	3840.37	4515.65	5190.93	36.75
37.00	1489.25	1831.50	2173.75	2516.00	3201.00	3885.00	4569.50	5254.00	**37.00**
37.25	1501.64	1848.53	2195.42	2542.31	3236.09	3929.87	4623.65	5317.43	37.25
37.50	1514.06	1865.62	2217.18	2568.75	3271.87	3975.00	4678.12	5381.25	37.50
37.75	1526.26	1882.28	2239.04	2595.31	3307.84	4020.37	4732.90	5445.43	37.75
38.00	1539.00	1900.00	2261.00	2622.00	3344.00	4066.00	4788.00	5510.00	**38.00**
38.25	1551.51	1917.28	2283.04	2648.81	3380.34	4111.87	4843.40	5574.93	38.25
38.50	1563.56	1934.62	2305.18	2675.75	3416.87	4158.00	4899.12	5640.25	38.50
38.75	1576.64	1952.03	2327.30	2702.81	3453.34	4204.37	4955.25	5705.43	38.75
39.00	1589.25	1969.50	2349.75	2730.00	3490.50	4251.00	5011.50	5772.00	**39.00**
39.25	1601.89	1987.03	2371.92	2757.31	3527.09	4297.87	5068.15	5838.43	39.25
39.50	1614.56	2004.62	2394.69	2784.75	3564.87	4345.00	5125.12	5905.25	39.50
39.75	1627.26	2022.28	2417.28	2812.31	3602.34	4392.37	5182.40	5972.43	39.75
40.00	1640.00	2040.50	2440.00	2840.00	3640.00	4440.00	5240.00	6040.00	**40.00**
40.25	1652.76	2057.78	2462.80	2867.81	3677.84	4487.87	5297.97	6107.93	40.25
40.50	1665.56	2075.62	2485.68	2895.75	3715.87	4536.00	5356.12	6176.25	40.50
40.75	1678.39	2093.53	2508.67	2923.81	3754.09	4584.37	5414.65	6244.93	40.75
41.00	1691.25	2111.50	2531.75	2952.00	3792.50	4633.00	5473.50	6314.00	**41.00**
41.25	1704.14	2129.53	2554.92	2980.31	3831.09	4681.87	5532.65	6383.43	41.25
41.50	1717.06	2147.62	2578.18	3008.75	3869.87	4731.00	5592.12	6453.25	41.50
41.75	1730.01	2165.78	2601.30	3037.31	3908.84	4780.37	5651.90	6523.43	41.75

BASE 31.—*Sectional Areas in Feet.*

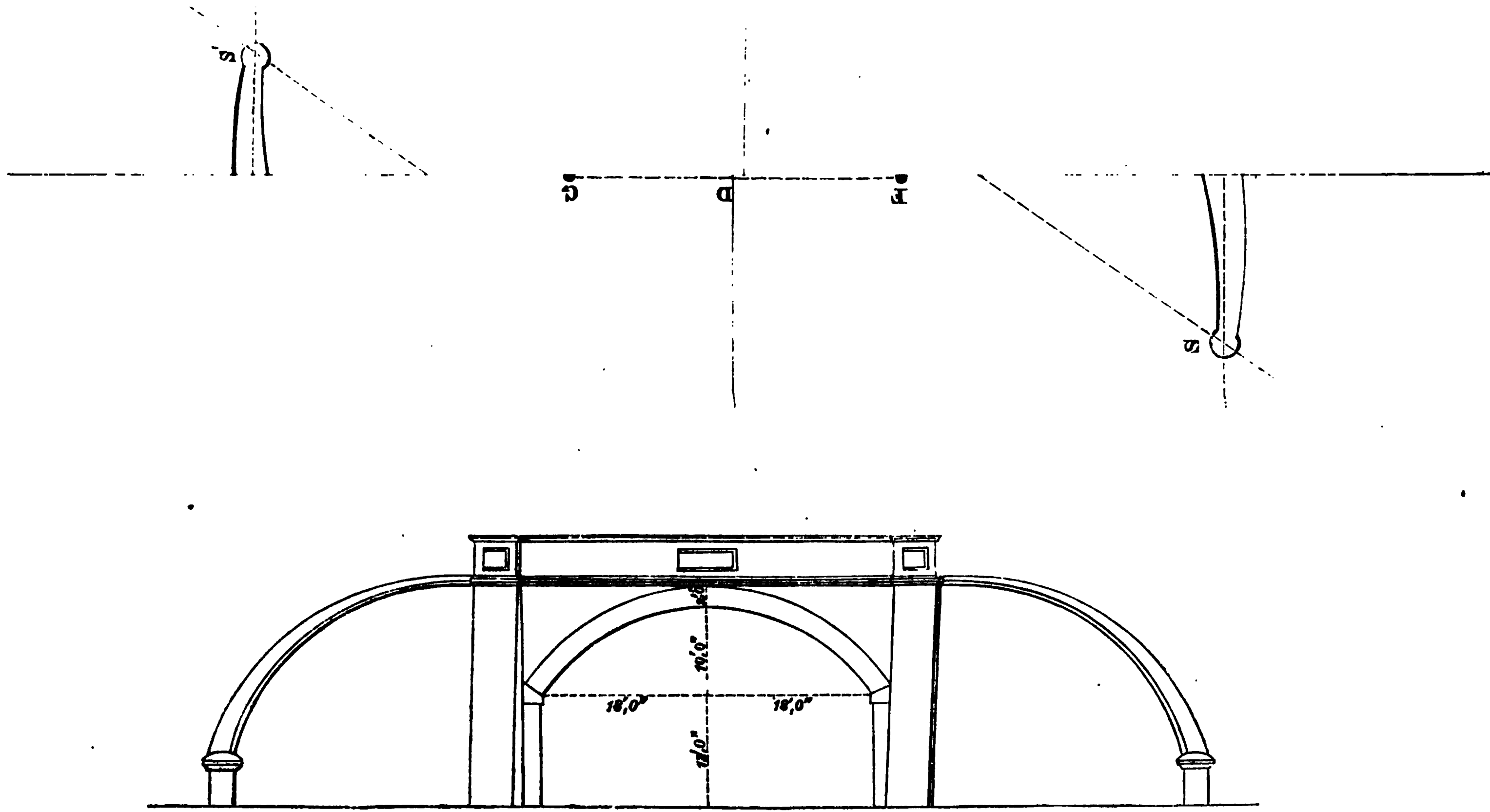
Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
42.00	1743.00	2184.00	2625.00	3066.00	3948.00	4830.00	5712.00	6594.00	**42.00**
42.25	1756.01	2202.28	2648.54	3094.81	3987.34	4879.87	5772.40	6664.93	42.25
42.50	1769.06	2220.62	2672.18	3123.75	4026.87	4930.00	5833.12	6736.25	42.50
42.75	1782.13	2239.02	2695.90	3152.80	4066.57	4980.35	5894.12	6807.90	42.75
43.00	1795.25	2257.50	2719.75	3182.00	4106 50	5031.00	5955.50	6880.00	**43.00**
43.25	1808.39	2276.03	3743.67	3211.31	4146.59	5081.87	6017.15	6952.43	43.25
43.50	1821.56	2294.62	2767.68	3240.75	4186.87	5133.00	6079.12	7025.25	43.50
43.75	1834.76	2313.28	2791.79	3270.31	4227.34	5184.37	6141.40	7098.43	43.75
44.00	1848.00	2332.00	2816.00	3300.00	4268.00	5236.00	6204.00	7172.00	**44.00**
44.25	1861.26	2350.78	2840.29	3329.81	4308.84	5287.87	6266.90	7245.93	44.25
44.50	1874.56	2369.62	2864.68	3359.75	4349.87	5340.00	6330.12	7320.25	44.50
44.75	1887.89	2388.53	2888.17	3389.81	4391.09	5392.37	6393.65	7394.93	44.75
45.00	1901.25	2407.50	2913.75	3420.00	4432.50	5446.00	6457.50	7470.00	**45.00**
45.25	1914.64	2426.53	2938.42	3450.31	4474.09	5497.87	6521.65	7545.43	45.25
45.50	1928.06	2445.62	2963.18	3480.75	4515.87	5550.00	6585.12	7621.25	45.50
45.75	1941.51	2464.78	2988.04	3511.31	4557.84	5604.37	6650.99	7697.43	45.75
46.00	1955.00	2484.00	3013.00	3542.00	4600.00	5658.00	6716.00	7774.00	**46.00**
46.25	1968.51	2503.28	3038.04	3572.81	4642.34	5711.87	6781.40	7850.93	46.25
46.50	1982.06	2522.62	3063.18	3603.75	4684.87	5766.00	6847.12	7928.25	46.50
46.75	1995.64	2542.03	3088.42	3634.81	4727.59	5820.37	6913.15	8005.93	46.75
47.00	2009.25	2561.50	3113.75	3666.00	4770.50	5875.00	6979.50	8084.00	**47.00**
47.25	2022.89	2581.03	3139.17	3697.31	4813.59	5929.87	7046.15	8162.43	47.25
47.50	2036.56	2600.62	3164.68	3728.75	4856.87	5985.00	7113.12	8241.25	47.50
47.75	2050.26	2620.28	3190.29	3760.31	4900.34	6040.37	7180.40	8320.43	47.75
48.00	2064.00	2640.00	3216.00	3792.00	4944.00	6096.00	7248.00	8400.00	**48.00**
48.25	2077.76	2659.78	3241.79	3823.81	4987.84	6151.87	7315.90	8479.93	48.25
48.50	2091.56	2679.62	3267.68	3855.75	5031.87	6208.00	7384.12	8560.25	48.50
48.75	2105.39	2699.53	3293.67	3887.81	5076.09	6264.37	7452.65	8640.93	48.75
49.00	2119.25	2719.50	3319.75	3920.00	5120.50	6321.00	7521.50	8722.00	**49.00**
49.25	2133.14	2739.53	3345.92	3952.31	5165.09	6377.87	7590.65	8803.43	49.25
49.50	2147.06	2759.62	3372.18	3984.75	5209.87	6435.00	7660.12	8884.25	49.50
49.75	2161.01	2779.78	3398.54	4017.31	5254.84	6492.37	7729.90	8967.43	49.75

BASE 31.—*Sectional Areas in Feet.*

Depths.	¼ to 1.	½ to 1.	¾ to 1.	1 to 1.	1½ to 1.	2 to 1.	2½ to 1.	3 to 1.	Depths.
50.00	2175.00	2800.00	3425.00	4050.00	5300.00	6550.00	7800.00	9050.00	**50.00**
50.25	2189.01	2820.28	3451.54	4082.81	5345.34	6607.87	7870.40	9132.93	50.25
50.50	2203.06	2840.62	3478.18	4115.75	5390.87	6666.00	7941.12	9216.25	50.50
50.75	2217.14	2861.03	3504.92	4148.81	5436.59	6724.37	8012.15	9299.93	50.75
51.00	2231.25	2881.50	3531.75	4182.00	5482.50	6783.00	8083.50	9384.00	**51.00**
51.25	2245.39	2902.03	3558.67	4215.31	5528.59	6841.87	8155.15	9468.43	51.25
51.50	2259.56	2922.62	3585.68	4248.75	5574.87	6901.00	8227.12	9553.25	51.50
51.75	2273.76	2943.28	3612.29	4282.81	5621.34	6960.37	8299.40	9638.43	51.75
52.00	2288.00	2964.00	3640.00	4316.00	5668.00	7020.00	8372.00	9724.00	**52.00**
52.25	2302.26	2984.78	3667.29	4349.81	5714.84	7079.87	8444.90	9809.93	52.25
52.50	2316.56	3005.62	3694.68	4383.75	5761.87	7140.00	8518.12	9896.25	52.50
52.75	2330.89	3026.53	3722.17	4417.81	5809.09	7200.37	8591.65	9982.93	52.75
53.00	2345.25	3047.50	3749.75	4452.00	5856.50	7261.00	8665.50	10070.00	**53.00**
53.25	2359.64	3068.53	3777.42	4486.31	5904.09	7321.87	8739.65	10157.43	53.25
53.50	2374.06	3089.62	3805.18	4520.75	5951.87	7383.00	8814.12	10245.25	53.50
53.75	2388.51	3110.78	3833.04	4555.31	5999.84	7444.37	8888.90	10333.43	53.75
54.00	2403.00	3132.00	3861.00	4590.00	6048.00	7506.00	8964.00	10422.00	**54.00**
54.25	2417.51	3153.28	3889.04	4624.81	6096.34	7567.87	9039.40	10510.93	54.25
54.50	2432.06	3174.62	3917.18	4659.75	6144.87	7629.00	9115.12	10600.25	54.50
54.75	2446.64	3196.03	3945.92	4694.81	6193.59	7692.37	9191.15	10689.93	54.75
55.00	2461.25	3217.50	3973.75	4730.00	6242.50	7755.00	9267.50	10780.00	**55.00**
55.25	2475.89	3239.03	4002.17	4765.31	6291.59	7817.87	9344.15	10870.43	55.25
55.50	2490 56	3260.62	4030.68	4800.75	6340.87	7881.00	9421.12	10961.25	55.50
55.75	2505.26	3282.28	4059.29	4836.31	6390.34	7944.37	9499.40	11052.43	55.75
56.00	2520.00	3304.00	4088.00	4872.00	6440.00	8008.00	9576.00	11144.00	**56.00**
56.25	2534.76	3325.78	4116.79	4907.81	6489.84	8071.87	9653.90	11235.93	56.25
56.50	2549.56	3347.62	4145.68	4943.75	6539.87	8136.00	9732.12	11328.25	56.50
56.75	2564.39	3369.53	4174.67	4979.81	6590.09	8200.37	9810.65	11419.93	56.75
57.00	2579.25	3391.50	4203.75	5016.00	6640.50	8265.00	9889.50	11514.00	**57.00**
57.25	2594.14	3413.53	4232.92	5052.31	6691.09	8329.87	9968.65	11607.43	57.25
57 50	2609.06	3435.62	4262.18	5088.75	6741.87	8395.00	10048.12	11701.25	57.50
57·75	2624.01	3457.78	4291.54	5125.31	6792.84	8460.37	10127.90	11795.43	57.75



b
A
B
d
c
ROCK



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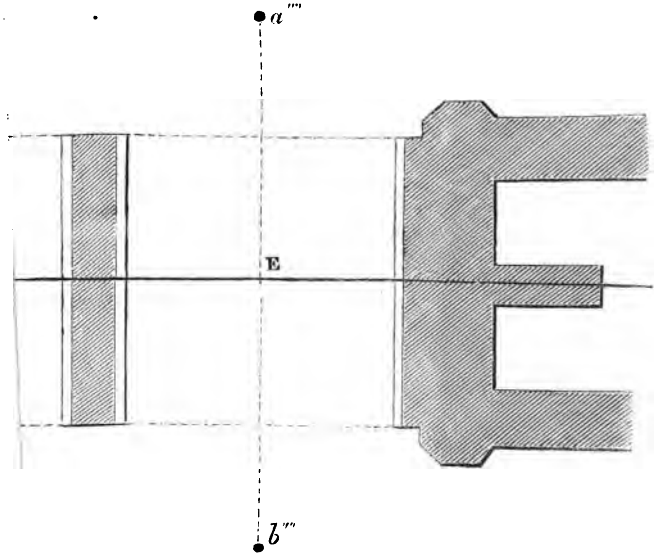
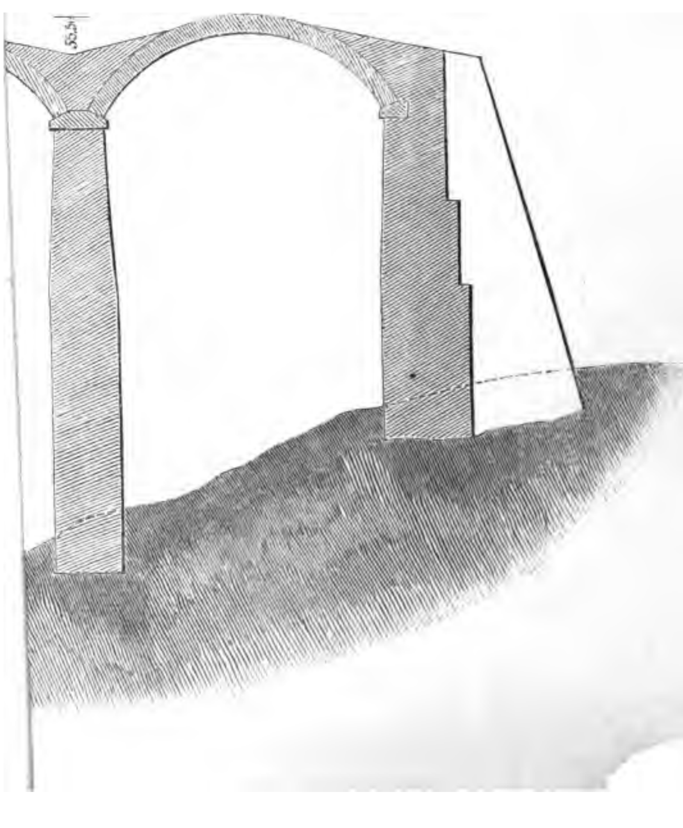

a''''
E
b''''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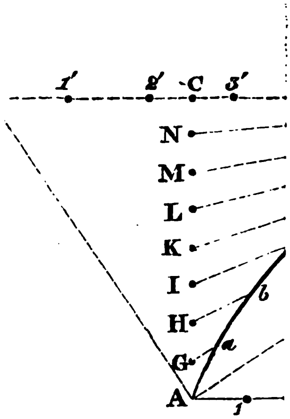
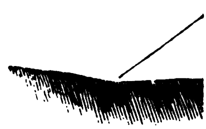
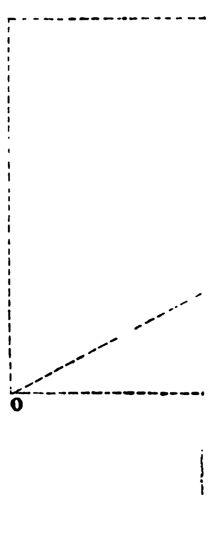

1′ 2′ C 3′
N
M
L
K
I
H
G
A
1
a
b

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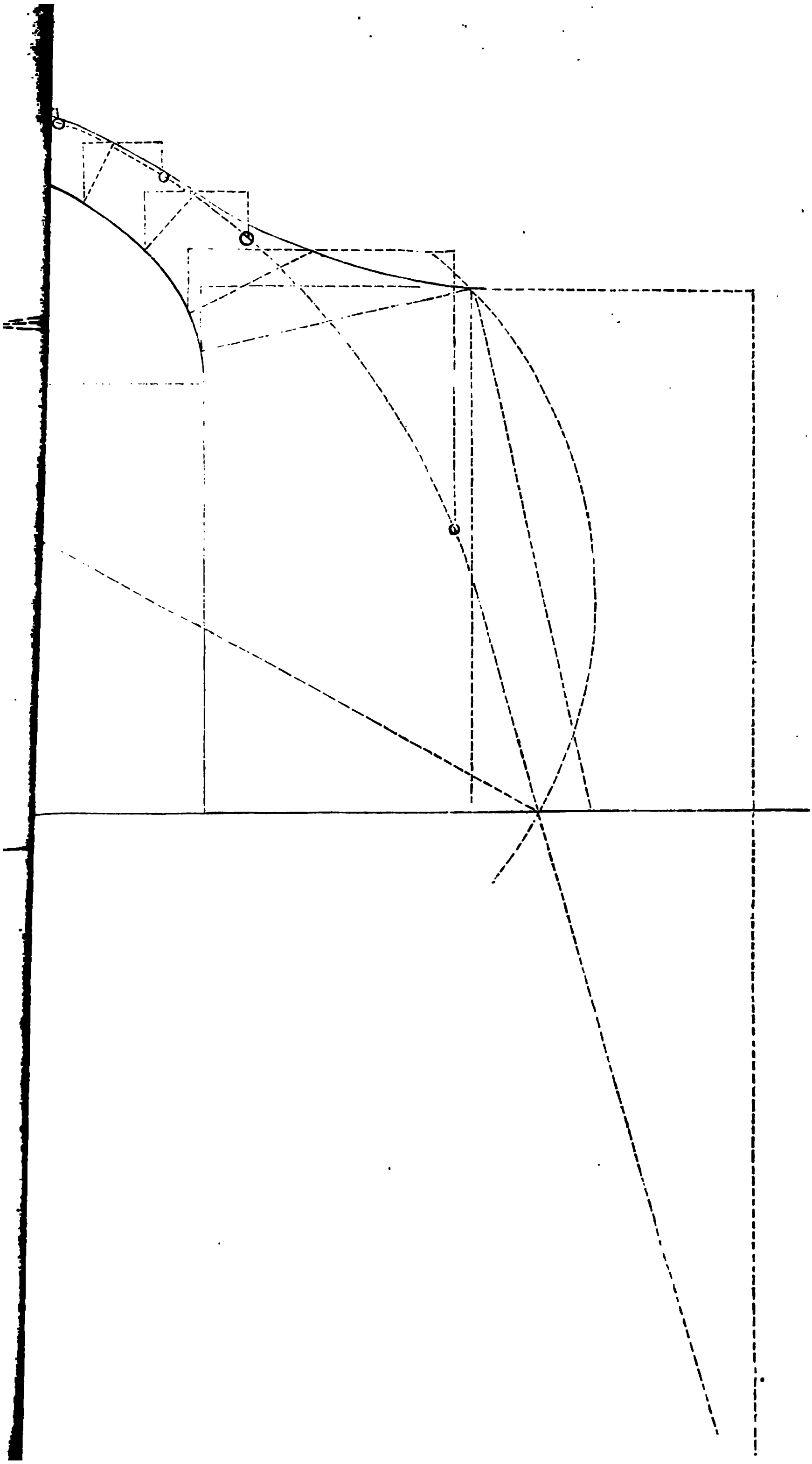

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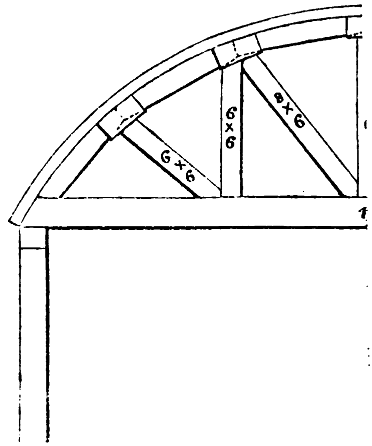
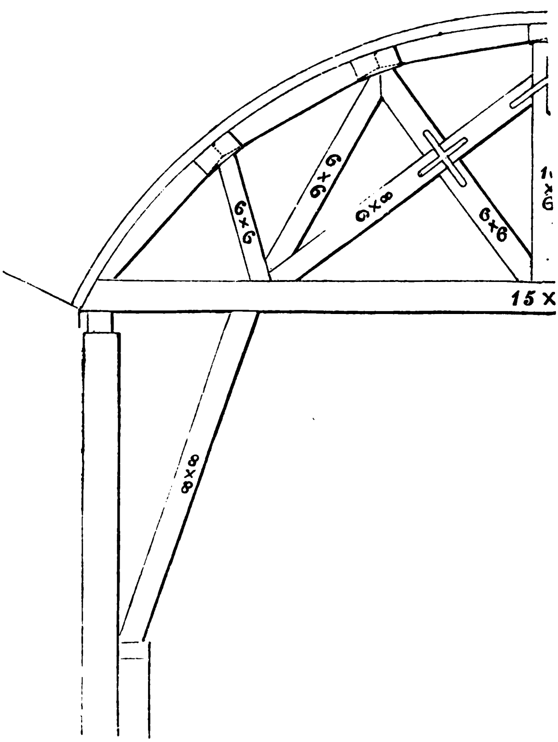
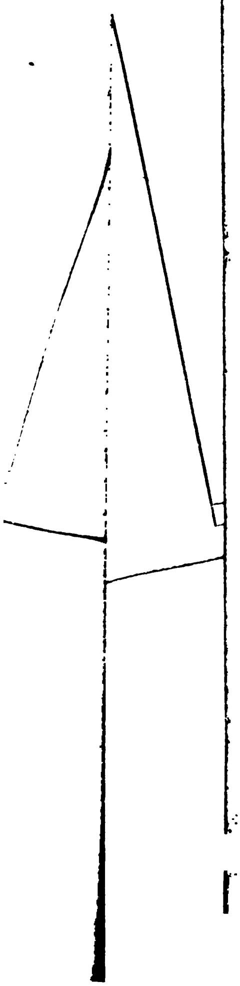
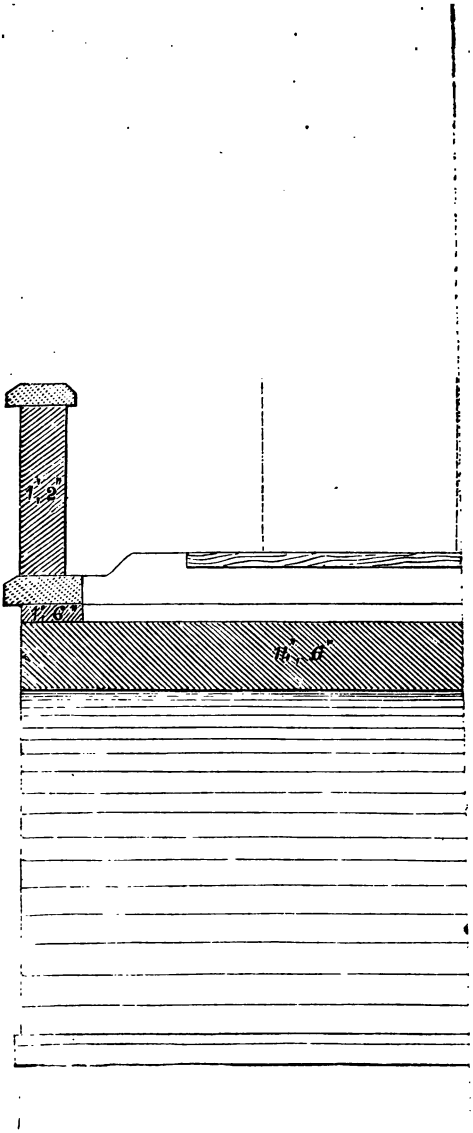


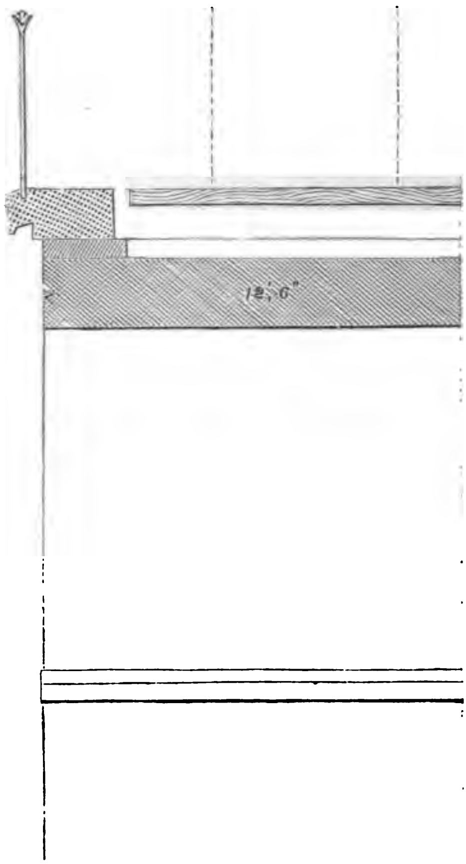
Fig

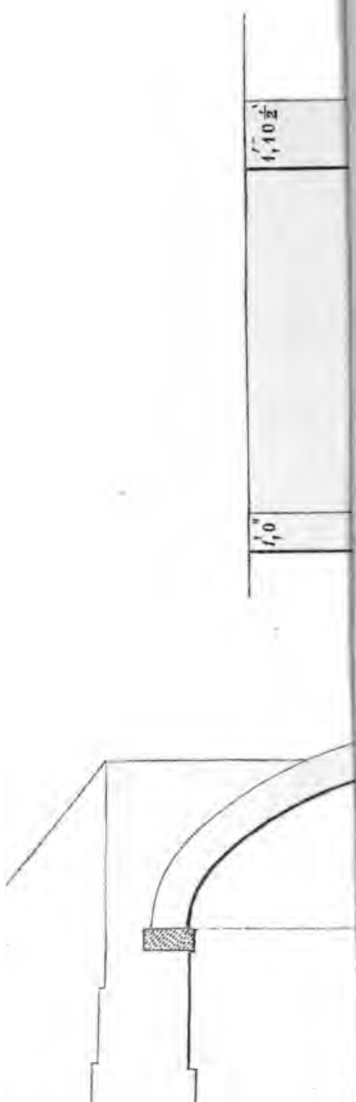


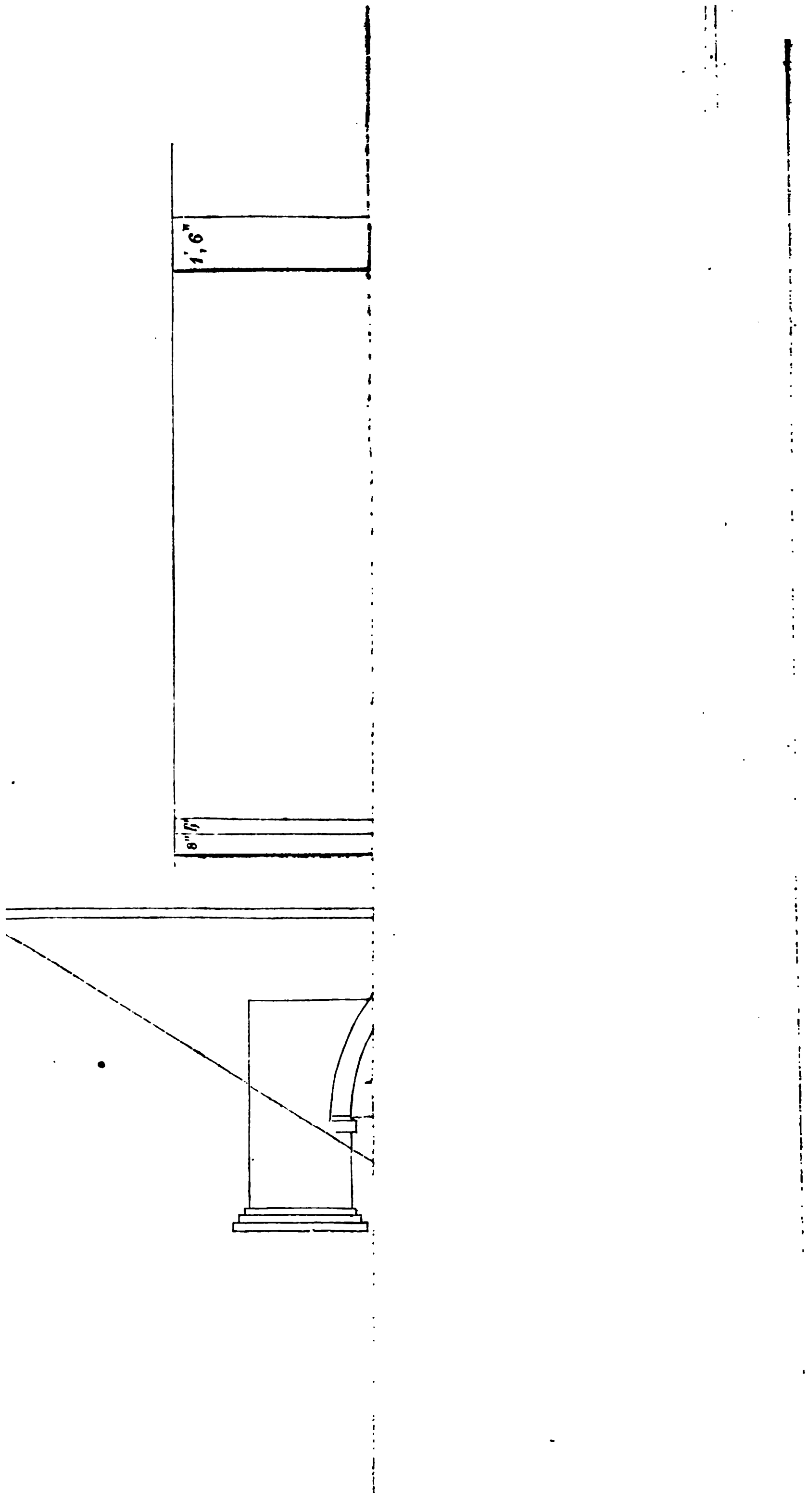


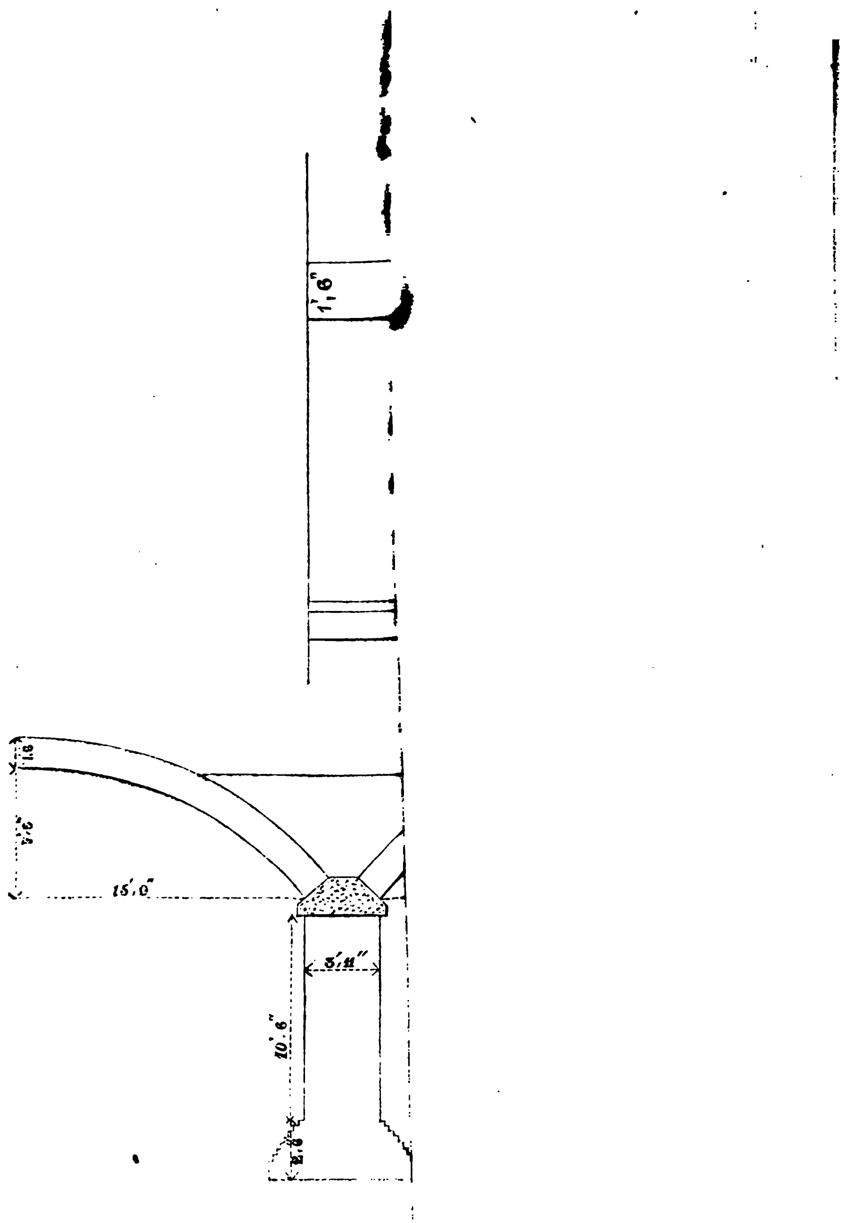


1' 2"
1' 6"
14' 6"

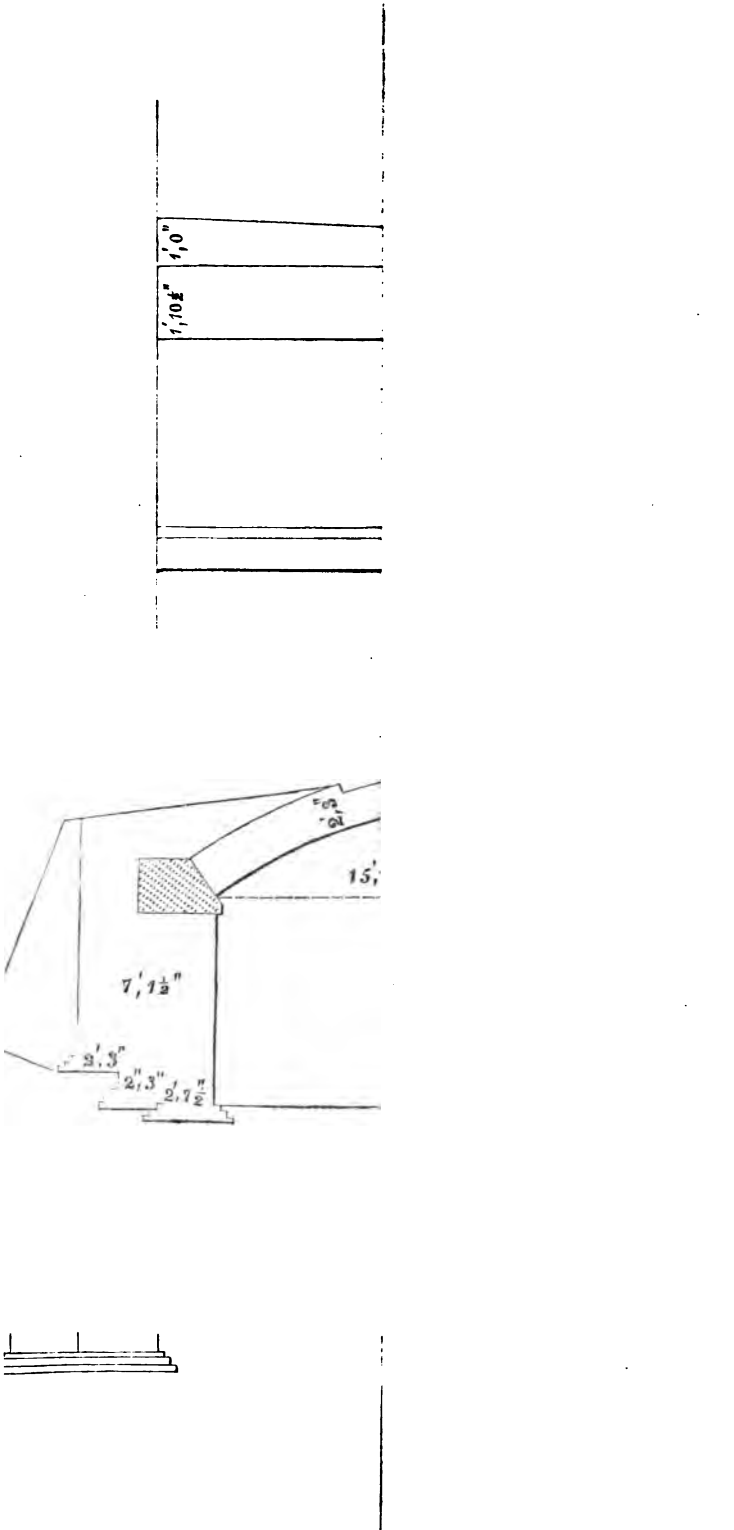



1',10½'
1',0"


1',6"
8"

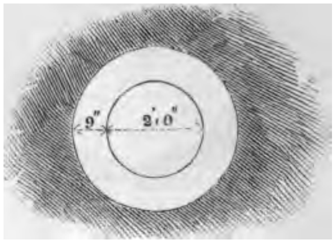


1'6"
15'0"
3'11"
10'6"



1',0"
1',10½"
7',1½"
2',3"
2',3"
2',7½"

Fig. 80.



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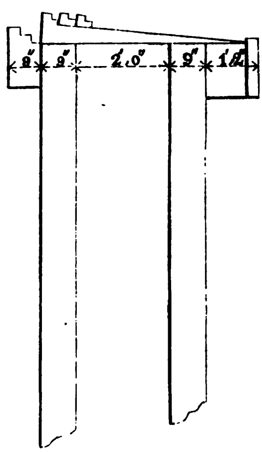

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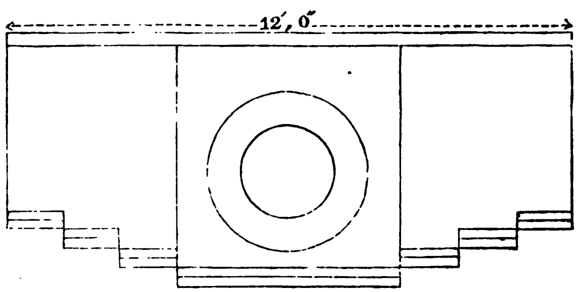

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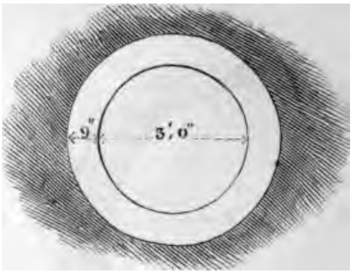

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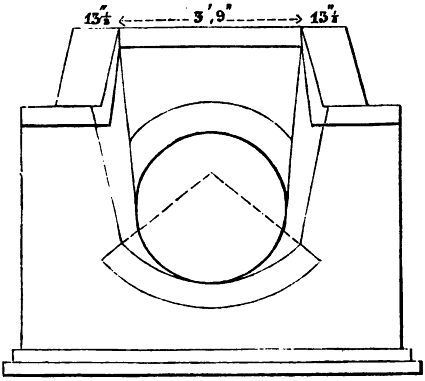

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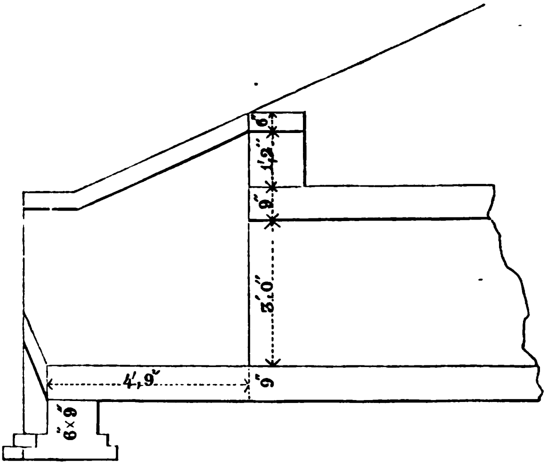

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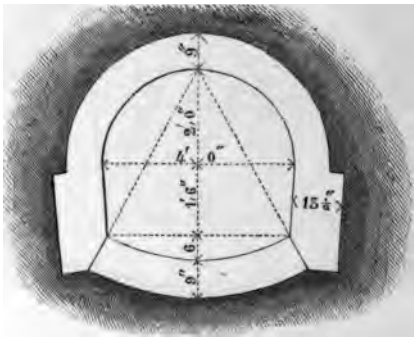

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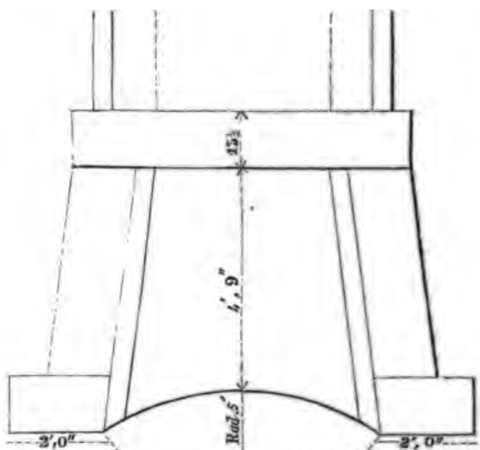

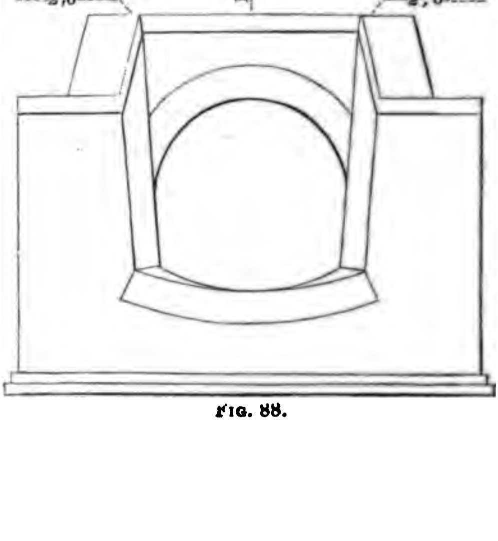

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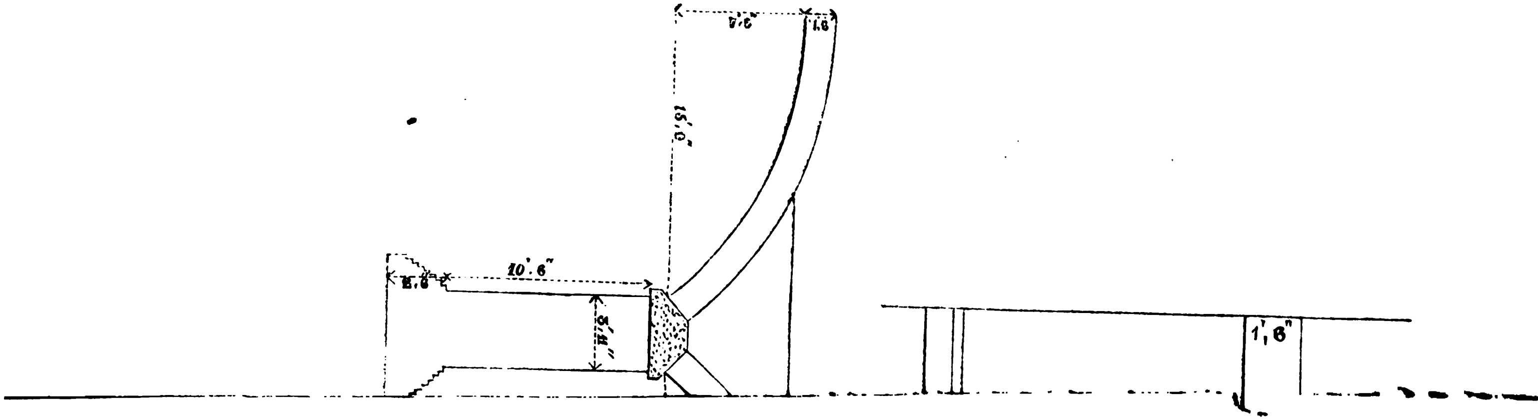


10'6"
1'6"

Fig. 94.

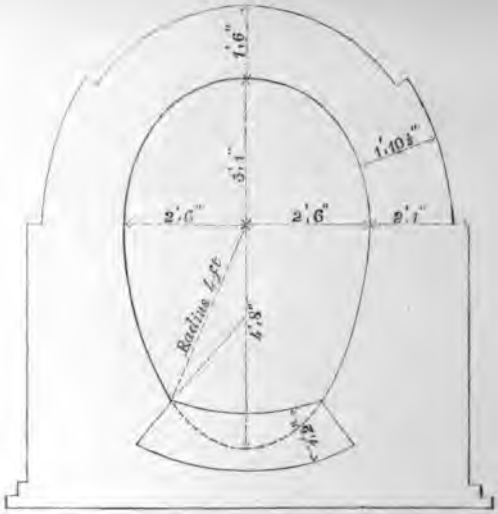
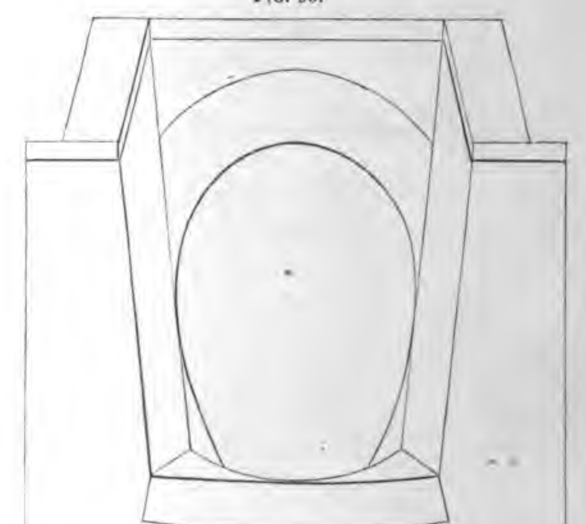
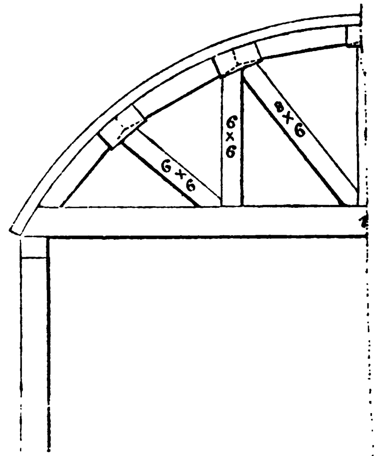


Fig. 95.



Fi



Fig

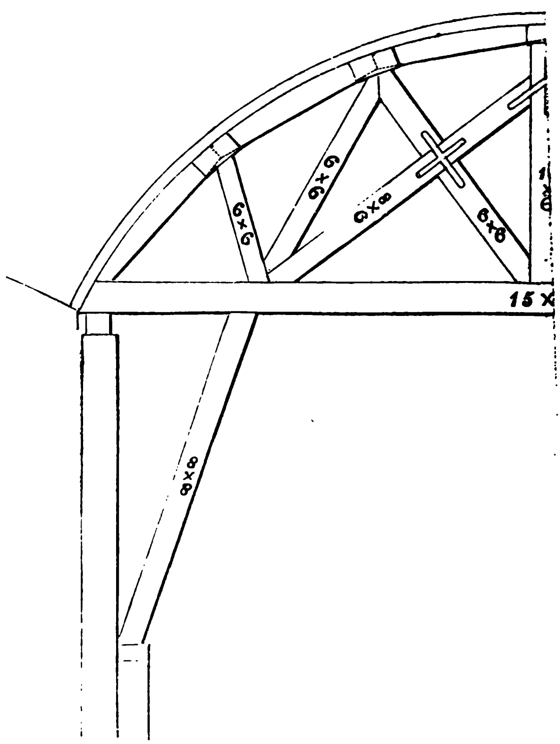
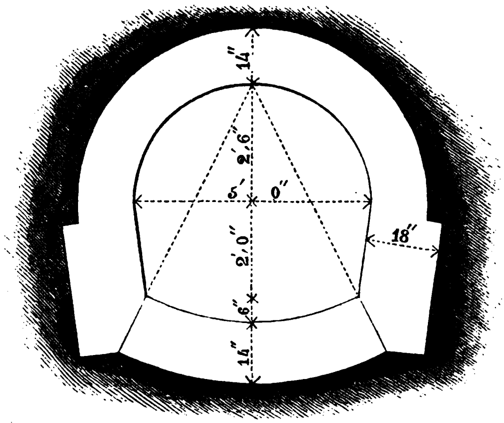


Fig. 89.



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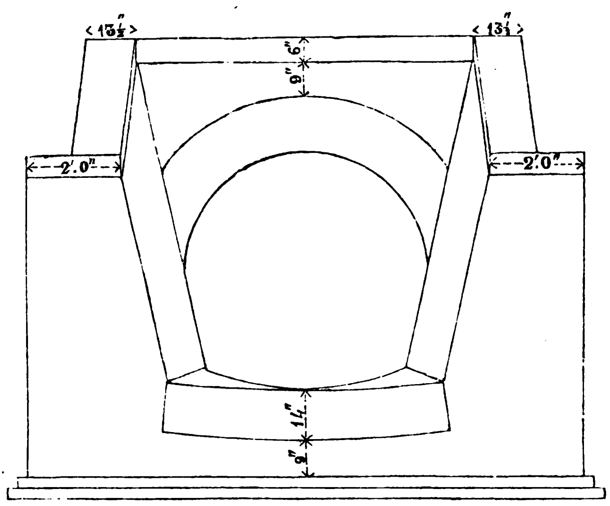

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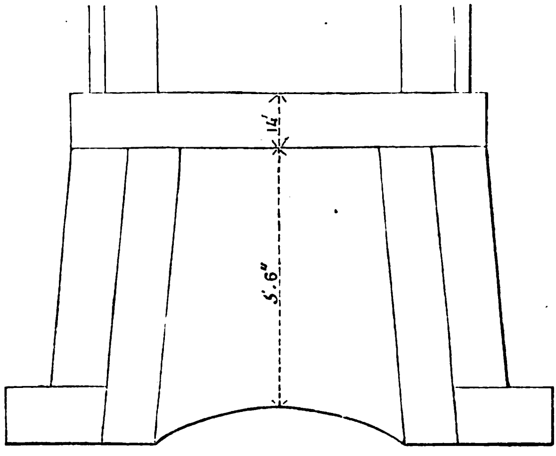

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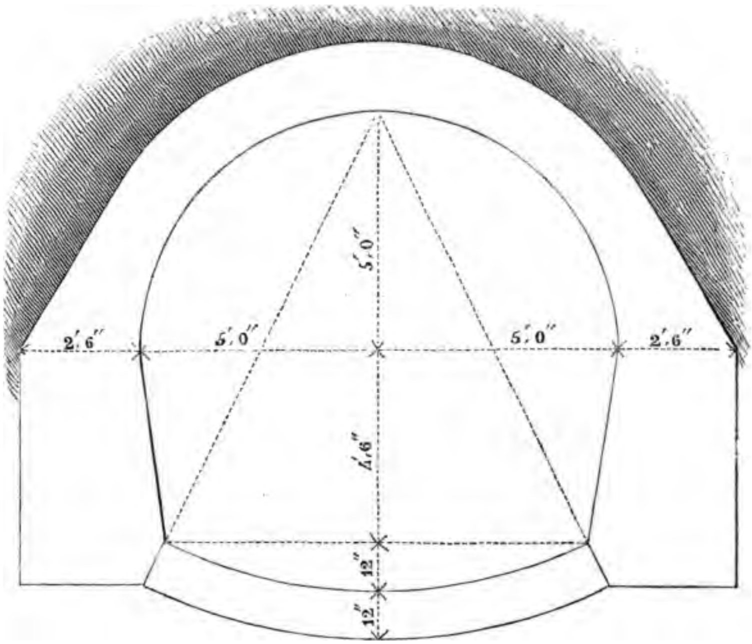

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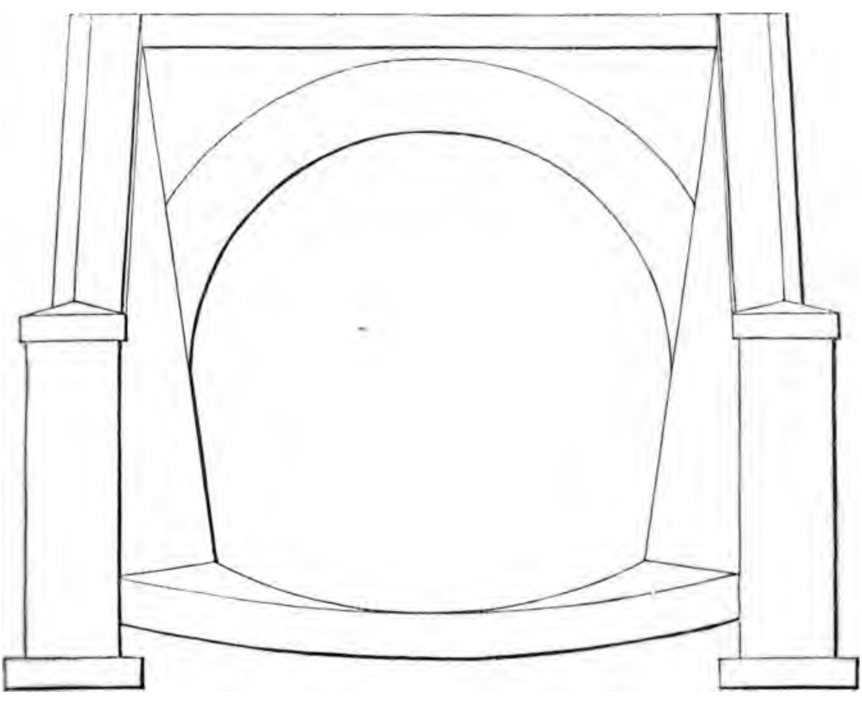

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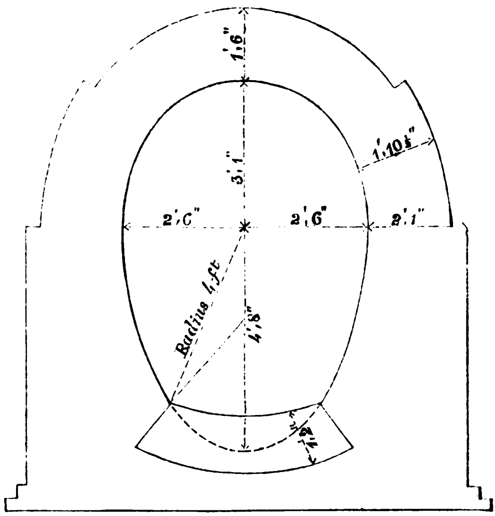

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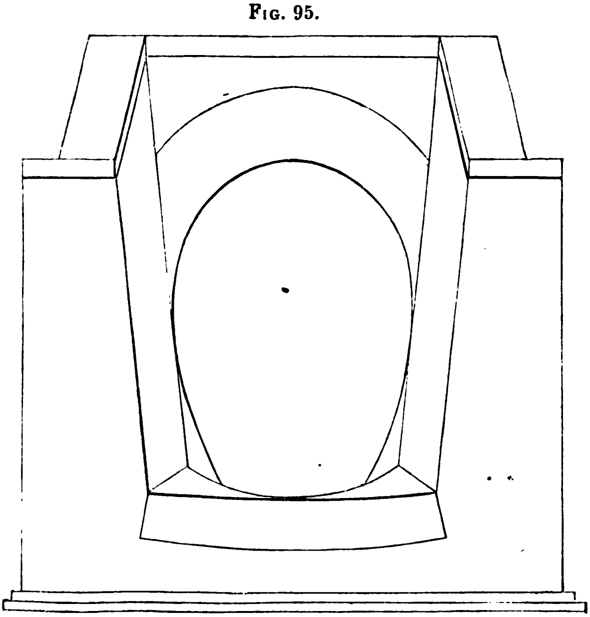

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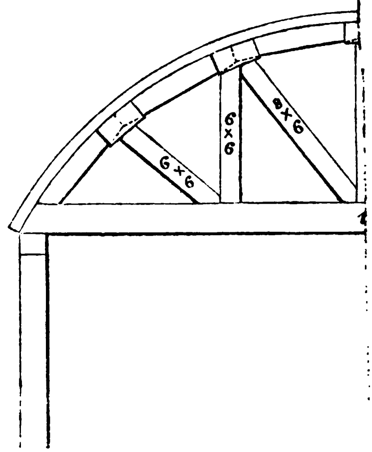

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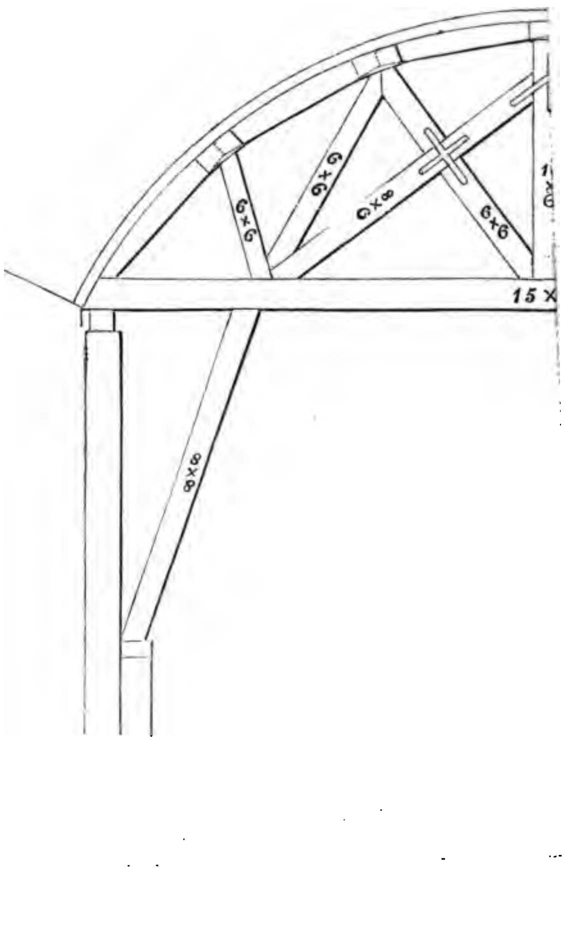

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